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Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water.

A. Locke, D.M. Reid, W.G. Sprules,
J.T. Carlton, and H.C. van Leeuwen

Great Lakes Laboratory for Fisheries
and Aquatic Sciences
Canada Centre for Inland Waters
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario
L7R 4A6

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Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water.

by

A. Locke[1], D.M. Reid[1], W.G. Sprules[1], J.T. Carlton[2]
and H.C. van Leeuwen[1]

Great Lakes Laboratory For Fisheries
And Aquatic Sciences,
Canada Centre for Inland Waters,
867 Lakeshore Road, P.O. BOX 5050,
Burlington, Ontario
L7R 4A6

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[1] Dept. of Zoology, Erindale College, University of Toronto,
Mississauga, Ontario, Canada, L5L 1C6
[2] Maritime Studies Program, Williams College,
Mystic Seaport, Mystic, Connecticut, 06355, U.S.A.

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ABSTRACT

Locke, A., D.M. Reid, W.G. Sprules, J.T. Carlton, and H.C. van Leeuwen. 1991. Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water: Can. Tech. Rep. Fish. Aquat. Sci. 1822

We studied ballast water carried by foreign ocean-going vessels into the Laurentian Great Lakes and upper St. Lawrence River from May to December 1990 in order to monitor compliance with the Great Lakes Ballast Water Control Guidelines and effectiveness of these guidelines in limiting occurrence of foreign freshwater and coastal organisms in ballast water. Compliance of vessels with the guidelines is 95 percent (all vessels) or 89 percent (excluding vessels not carrying ballast water). Effectiveness of mid-ocean ballast water exchange in eliminating live freshwater zooplankton from ships originating in freshwater ports is 67 percent. Some risk of invasions still exists since some ships do not comply with the guidelines, live freshwater organisms may still exist after mid-ocean exchange, and foreign organisms are released in fresh and brackish parts of the St. Lawrence River which supply much of the ballast water released in the Great Lakes.

RESUME

Locke, A., D.M. Reid, W.G. Sprules, J.T. Carlton, and H.C. van Leeuwen. 1991. Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water: Can. Tech. Rep. Fish. Aquat. Sci. 1822

Nous avons étudié l'eau de ballast transportée par des navires de haute-mer étrangers qui ont navigué dans les Grands Lacs laurentiens et la partie supérieure du fleuve Saint-Laurent, entre mai et décembre 1990, afin de vérifier s'ils respectaient les Lignes directrices sur le contrôle des ballasts d'eau dans les Grands Lacs, et si ces lignes directrices permettaient vraiment de limiter la présence d'organismes dulcicoles et côtiers étrangers dans l'eau de ballast. Les lignes directrices sont respectées dans une proportion de 95 pour cent (tous les navires) ou de 89 pour cent (en excluant les navires qui n'ont pas d'eau de ballast). L'efficacité de l'échange de l'eau de ballast au milieu de l'océan en vue d'éliminer le zooplnncton dulcicole vivant des navires en provenance de ports d'eau douce est de 67 pour cent. La possibilité d'invasions demeure toujours étant donné que certains navires ne respectent pas les lignes directrices, que des organismes dulcicoles vivants peuvent encore exister même après l'échange au milieu de l'océan, et que des organismes étrangers sont libérés dans les secteurs d'eaux douces et saumâtres du fleuve Saint-Laurent qui fournissent une grande partie de l'eau de ballast rejetée dans les Grands Lacs.

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1.0. INTRODUCTION

The accidental introductions of at least three exotic European freshwater organisms in the Great Lakes in the 1980s (a predatory water flea, *Bythotrephes cederstroemi* Schoedler ; a predatory fish, *Gymnocephalus cernuus* (Linnaeus) ; and a filter-feeding mussel, *Dreissena polymorpha* Pallas) are believed to have been mediated by unintentional intercontinental transfers in the ballast water of ocean-going vessels (Mills *et al.*, 1991). Concern over the potential for further introductions of unwanted species led to the initiation of measures controlling the release of foreign ballast water destined for the Great Lakes. On May 1 1989, guidelines were set into place by the Canadian Coast Guard (CCG) requesting voluntary exchange of ballast water of upbound ocean-going vessels in the open sea prior to arrival at the St. Lawrence Seaway. In this document we report the results of a study of ballast water exchange and compliance rates based on foreign vessels entering the St. Lawrence Seaway between May and December, 1990.

The intent of the voluntary 'Great Lakes Ballast Water Control Guidelines' (Appendix A) is that ships destined for the St. Lawrence Seaway and Great Lakes replace all ballast taken on in fresh or coastal marine waters with mid-ocean water. Under the 1989 guidelines, ships upbound in the Seaway beyond Montreal could carry only ballast water which was taken on in ocean depths greater than 2000 metres. Ships unable to exchange ballast water in mid-ocean (e.g. those which have not left the North American continental shelf) could exchange ballast water within the Laurentian Channel, east of longitude 64° W, in water depths exceeding 340 metres. The rationale for mid-ocean ballast exchange is that freshwater or coastal organisms would be flushed out or killed by high salinity water. Mid-ocean organisms imported in saltwater ballast would be unlikely to survive after release in the Great Lakes. Any residual foreign freshwater organisms remaining in the ballast tank following the mid-ocean exchange would theoretically be killed by the influx of salt water, since the critical upper salinity limit for most freshwater species is 5 to 8 °/oo (Levinton, 1980). The overall goal of the ballast water guidelines is the elimination of unplanned introductions of new aquatic species to the Great Lakes basin.

This study was designed:

(1) To determine the extent of compliance of inbound ocean-going vessels with the ballast water exchange guidelines using chemical (salinity) and biological (planktonic) techniques.

(2) To establish, using biological (planktonic) techniques, the effectiveness of open-ocean exchange of ballast water in reducing or eliminating the presence of freshwater and brackishwater organisms in ballast water scheduled for discharge in the Great Lakes and upper St. Lawrence River. We assumed that if freshwater zooplankton

are found, other types of freshwater organisms are probably present.

(3) To determine the geographic and seasonal variations in the patterns of diversity, abundance, and density of foreign planktonic species arriving in ballast water scheduled for release in the Great Lakes.

(4) To assess the relative level of risk that (a) the organisms in non-exchanged ballast water, and (b) the residual organisms in exchanged water, pose to the Great Lakes ecosystem.

2.0. METHODS

Compliance with the voluntary guidelines was primarily determined using information supplied by the vessels' operators and available through various Canadian government sources (Section 2.1). Selected vessels (Section 2.2) were boarded by the sampling team for collection of physico-chemical (salinity, temperature) and biological (picoplankton, zooplankton) samples, which were used to confirm the vessel's ballast water status and to determine the effectiveness of any reported exchange (Section 2.3).

2.1. SOURCES OF INFORMATION

Ballast water information was obtained for ocean-going foreign (non-Canadian and non-American registry) vessels upbound in the St. Lawrence River, from various CCG and St. Lawrence Seaway Authority (SLSA) sources (see Appendix B). The current ballast water status (ballast water on board at Montreal) and recent ballast water history (previous ballast water) of most vessels was determined from these sources before the vessels reached Montreal. This information was used to determine which vessels would be boarded and sampled. Use of CCG and SLSA sources to track movements of vessels approaching the Seaway was also necessary in order to determine the time of arrival at Montreal of vessels to be sampled, and whether vessels would be sampled in Montreal Harbour or during transit of the Montreal Seaway locks.

Only foreign vessels were sampled in this study because their movements were easier to track than Canadian- or American-registered vessels, which do not require pilots and thus have fewer interactions with Canadian regulatory agencies prior to entering the Seaway. As well, most Canadian and American vessels carried only ballast water from ports within the St. Lawrence River - Great Lakes system.

Copies of all 1990 Ballast Water Exchange Reports (BWERs, see Appendix C) returned by either the ship's captain or senior officers, as well as more general information on vessel traffic since 1986, were obtained from the SLSA. Information contained in the BWERs was used to supplement data obtained from other sources.

2.1.1. Determining compliance with Great Lakes Ballast Water Control Guidelines from vessel traffic information

Compliance of vessels with the GLBWCG was determined based on information obtained from CCG and SLSA sources (section 2.1), ballast water exchange reports (section 2.1) and ballast water data sheets (section 2.3).

In conformance with current Coast Guard practices, we considered vessels to be in compliance with the guidelines if they:

(1) carried no ballast water

(2) carried only unpumpable ballast water

(3) carried permanent ballast water

(4) carried ballast water that was not intended to be discharged in the Great Lakes (whether this water had been exchanged according to the GLBWCG or not)

(5) carried ballast water that had been exchanged offshore or in the Laurentian Channel as requested by the GLBWCG.

We calculated compliance rates for 1990 based on all foreign ocean-going vessels carrying known ballast water.

2.1.2. Other uses of vessel traffic information

Vessels were categorized by source of ballast water carried at the time of entry to the Seaway ('current' ballast water) in order to determine the extent to which various regions contribute to ballast water entering the St. Lawrence Seaway. Sources of previous ballast water prior to exchange or discharge were also tabulated in order to determine what the composition of ballast water entering the seaway would have been had the GLBWCG not been initiated.

The volume of ballast water carried into the Great Lakes system during 1990 was calculated from average volume of known ballast water carried by incoming vessels.

In order to determine the extent of foreign ballast water discharge into Canadian inshore or fresh waters, the numbers of vessels known to have discharged ballast water in the Laurentian Channel, St. Lawrence River or Montreal Harbour were tabulated. The volume of water carried to Montreal by vessels not entering the Seaway (i.e. water likely to be discharged by vessels taking on cargo in Montreal) was calculated. The volume of freshwater ballast entering the Seaway, originating from the St. Lawrence River or from river ports (Montreal, Quebec, Sorel, Contrecoeur) was also calculated. These volumes are of interest because of the possibility that organisms dumped in Montreal Harbour or downstream freshwater portions of the St. Lawrence River may be picked up by ships taking on ballast in Montreal Harbour or in the river, and carried

2.2. SELECTION OF VESSELS FOR SAMPLING

Information obtained before ships arrived in Montreal was used to determine which vessels would be boarded and sampled. Vessels were prioritized for sampling according to their ballast characteristics, as follows:

(1) vessels carrying unexchanged foreign fresh water

(2) vessels originally carrying foreign fresh water or coastal salt water which had been replaced by domestic fresh water

(3) vessels originally carrying foreign fresh water or coastal salt water which had been replaced by oceanic salt water

(4) vessels carrying unexchanged coastal salt water

(5) vessels originally carrying coastal salt water which had been replaced by oceanic salt water.

2.3. BOARDING AND SAMPLING VESSELS

Targetted vessels were boarded by a sampling team of two while transiting the St. Lawrence Seaway between St. Lambert Lock #1 and Côte St. Catherines Lock #2 (approximately 1 to 1.5 hours transit time), or while docked in Montreal Harbour. The ballast water status was confirmed by discussion with the vessel's captain or senior officers, a ballast water sample was taken where possible, and a ballast water data sheet was completed (see Appendix D).

Ballast water was obtained either by lowering sampling gear through a manhole into a ballast tank or by pumping ballast water through a deck tap. Samples and data collected aboard each ship included (1) temperature and salinity measurements from a water sample, (2) picoplankton, and (3) zooplankton.

2.3.1. Physico-chemical and picoplankton samples

Salinity was examined as an indicator of compliance rates. Picoplankton was collected as a possible alternative indicator of salinity which might be able to distinguish between estuarine waters and mixtures of high and low salinity waters, two conditions that are otherwise not distinguishable from salinity measurements alone.

Water was collected in a plastic pail for temperature and salinity measurements and for picoplankton sampling. Temperature was measured immediately using a mercury field thermometer (Ertco K-5352). A 500-ml unfiltered water sample was returned to the field laboratory for measurement of salinity using a refractometer (Atago S-10, NSG Precision Cells, Inc., Farmingdale, NY). A 10-ml unfiltered water sample for picoplankton analysis was preserved in 4 percent formalin in a glass scintillation vial and kept cool during transport to M. Munawar at the Great Lakes Laboratory for

sample for picoplankton analysis was preserved in 4 percent formalin in a glass scintillation vial and kept cool during transport to M. Munawar at the Great Lakes Laboratory for Fisheries and Aquatic Sciences, Burlington, Ontario. Samples were fixed and enumerated with the DAPI procedure (Munawar & Weisse, 1989; Weisse & Munawar, 1989).

2.3.2. Zooplankton sampling

Zooplankton were collected by pumping water from a deck tap through a plankton net or by removing a hatch and hauling the net vertically through the water in the ballast tank.

Zooplankton samples were obtained by filtering water samples through 41-µm and 110-µm Nitex mesh plankton nets (Appendix F). A few samples were taken with a net of 53-µm mesh before the 41-µm mesh net was available. The number of zooplankton samples collected on each vessel ranged from one to five samples per ship (Appendix F), usually taken from a single ballast tank (two tanks were sampled on two vessels).

Zooplankton collected from the ballast tanks were rinsed from the nets and returned unpreserved to the field laboratory at Côte St. Catherine. Samples were immediately investigated under a dissecting microscope in order to determine which zooplankton were alive at the time of collection and also to obtain preliminary qualitative estimates of organism abundance in general taxonomic categories. These preliminary analyses were completed within 2 to 3 hours of sample collection. Zooplankton were stained with a 'vital stain' (bacto-neutral red), which stains active mitochondria (Sumner, 1969), and preserved in 4 percent sucrose-formalin mixture, buffered with 10 percent magnesium carbonate (Lind, 1979). Zooplankton samples were returned to the laboratory in Toronto for detailed taxonomic analysis of samples from vessels with salinity < 30 °/oo, those which had not exchanged ballast water, and those which had originated from a freshwater port and exchanged ballast in salt water. Specimens from these samples were enumerated and identified to species where possible.

2.3.3. Sampling sediments for zooplankton

On some ships where samples were taken through a manhole, sediment samples were collected after other sampling procedures had been completed. The sampling net was lowered to the bottom of the ballast tank and quickly raised and lowered again several times in an attempt to bring some of the sediment into the water column. Sediment samples (usually 10 to 15 ml) were returned to the field laboratory at Côte St. Catherine and cultured in 4 -litre glass jars filled with 2 l distilled water and 100

ml algal culture (*Isochrysis* sp.), oxygenated with an aquarium pump. Samples were cultured for four weeks at room temperature (approximately 22° C), then filtered through 41-µm Nitex mesh and examined using a dissecting microscope.

2.4. SAMPLING IN MONTREAL HARBOUR

Four sets of picoplankton and zooplankton samples were collected using a small boat in Montreal Harbour (between dock sections 40 and 67) on October 17 1990, to determine if foreign organisms were present due to extensive deballasting of upbound vessels in the harbour. Surface picoplankton were collected using a plastic pail. Zooplankton were collected by 10-m vertical tows of plankton nets (Appendix F). Samples were processed in the same way as those collected from ballast tanks.

3.0. RESULTS & DISCUSSION

3.1. SOURCES OF INFORMATION

Sources of information about vessel movements and ballast water status (primarily Transport Canada, including the CCG offices, and the SLSA; summarized in Appendix B) varied in their utility and reliability. To aid possible future studies, we evaluated these sources of information.

The Marine Transit List (MTL) was generally very useful, usually giving at least 24 hours notice of vessels arriving in Montreal Harbour or entering the Seaway. However, vessels stopping at intermediate ports such as Quebec City or Sorel would not show Montreal or the Great Lakes as their destination until they had departed their last stopover prior to Montreal. Additionally, many vessels either stopping in Montreal Harbour before entering the Seaway or travelling directly into the Seaway would continue to show Montreal as their destination until a pilot had actually been ordered for the upbound trip into the Seaway. In some cases, very little advance notice was possible.

ECAREG (Eastern Canadian Region, Vessel Traffic Service) and the CICS (Customer Information Control System) database were always helpful, but limited by the highly variable ballast water information initially recorded in the database. Much of this variability was apparently a result of individual interpretation of the original radio-telegram replies from the vessels by different operators. Also, of the 455 foreign, ocean-going vessels transitting the Seaway upbound in 1990, it appears that 13 vessels (2.9%) were never requested for ballast water information, 33 vessels (7.3%) never replied to the request, and at the end of the season no ballast water record could be found in the CICS database for 116 vessels (25.5%).

The RIC (Regional Information Centre, Transport Canada) and the DADS (Data Acquisition and Display System) database were always useful in locating vessels in the St. Lawrence - Great Lakes system. At our level of security clearance this was essentially the only useful information we could acquire from these sources.

The St. Lawrence Seaway Authority Inspectors were always as helpful as possible with respect to the vessels inspected - approximately 20 percent of the vessel traffic. On those occasions when a vessel departed upbound immediately after inspection, however, little or no time remained for communication between the inspectors and the sampling team.

Various vessel agents were of limited assistance. Direct communication was occasionally possible between the sampling team and onboard representatives of the agents, otherwise cargo status or schedules were usually the only information available.

The Vessel Traffic System (VTS) was always very helpful, and supplied some of the most reliable and up-to-date information. Direct radio contact between VTS and the onboard pilot allowed specific ballast water information to be passed on to the sampling team.

Cornwall and Montreal Pilotages were helpful, but due to vagaries of vessel traffic scheduling, pilotage order times could change drastically. Actual departures of vessels from Montreal varied from a few hours before to several days after anticipated departure times. Continuous updates were often required in order to meet some vessels for sampling.

Saint Lawrence Seaway Authority Control was always very helpful and useful especially when last-minute decisions about boarding at St Lambert were required. Along with VTS, they supplied the most reliable and up-to-date information on vessel movements.

Eisenhower (Ike) Control at the Eisenhower lock in the American part of the Seaway was used to a limited extent near the end of the sampling season. They were very helpful in contacting downbound vessels for ballast water information.

The BWERs (see Appendix C) were of limited use, due to poor return rates and incomplete data recorded. Only 178 BWERs were returned from the 455 foreign, ocean-going vessels monitored, a return rate of 39.1 percent. Even in the month of September, when special efforts were made by the SLSA to increase the number of returns, only 20 BWERs were received from 44 vessels (45.5% return rate). Usually, only information on the ballast water currently carried was recorded. It was seldom apparent from the reports if the vessels had actually exchanged ballast water or simply filled an empty ballast tank. When exchange had taken place, the source of the previous ballast water was seldom recorded. Six different versions of ballast water reports were seen; some of these seem to have originated with ship's officers or foreign shipping organizations. The official forms were generated by the CCG, handed to the ships officers by pilots at Les Escoumens (or by SLSA inspectors at Montreal), and returned

to the SLSA lockmasters at lock #1 or #2.

3.2. BALLAST WATER CHARACTERISTICS OF UPBOUND VESSEL TRAFFIC

3.2.1. Extent of compliance with the GLBWCG

During the 1990 shipping season, 455 foreign ocean-going vessels entered the St. Lawrence Seaway upbound from outside the St. Lawrence River system (Appendices H, I and J). An additional 19 vessels, including tugs, barges, research vessels, cruise ships, and ships of Canadian registry, and 915 lakers, were not included in the study. No ballast water information was available for 44 vessels, most of which entered the Seaway before initiation of our study. Of the remaining 411 vessels, 213 carried no ballast water, 177 carried ballast water in compliance with the GLBWCG and 21 carried ballast water not in compliance with the GLBWCG (Figure 1). Calculated following CCG procedures, compliance was 95 percent [100(213 + 177)/411]. We prefer to calculate compliance including only vessels carrying ballast water. Thus, 89 percent of vessels carrying ballast water were in compliance [(100 x177)/411-213].

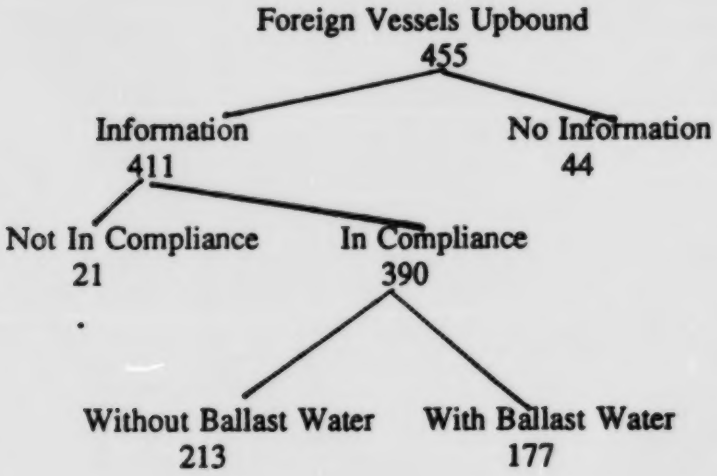

Figure 1. Dendogram separating upbound vessels into categories based on known ballast water characteristics.

Our overall conclusion based on data provided by the vessel's officers is that compliance with the voluntary guidelines is high, but that in part this is an artifact of criteria used to judge compliance. We feel that the following important issues need to be addressed;

(1) Many ships that reported 'no ballast water on board' may in fact have carried large volumes of unpumpable ballast water. In our study, only 12 ships reported unpumpable ballast water. Eleven of these ships reported 'no ballast water on board' (but then reported unpumpable water), and only one reported unpumpable water as 'ballast water on board' in the BWER. Seven of these ships reported a quantity of unpumpable ballast water which ranged from from 59 to 468 tonnes, with a mean of 157.7 tonnes. This may be considered an insignificant amount of water relative to a fully ballasted ship but could potentially contain a large number of planktonic organisms. We are concerned that organisms carried in the unpumpable water will become available for discharge as soon as more water is added to the ballast tank, and that these organisms could be released into the Great Lakes from vessels with multiple destinations in the Great Lakes.

(2) According to the present guidelines, no distinction was made between full and partial exchange by the CCG, and 11 ships which had only partially exchanged ballast water were considered to be 'in compliance'. Incomplete exchange probably cannot flush all organisms from the ballast tank, and may not achieve salinities lethal to any remaining freshwater organisms. We believe that these ships should not be considered to be 'in compliance'.

(3) We feel that vessels that report that they will not discharge ballast water in the Great Lakes (16 vessels) should not be automatically considered to be in compliance. We have no data to allow us to determine how often these vessels do discharge water in the Great Lakes but we assume this must happen occasionally due to change of plans occasioned by opportunities to pick up additional cargo, etc.

3.2.2. Sources of ballast water entering the Seaway

Sources of previous (i.e. pre-exchange) and current (post-exchange; identical to previous ballast water in cases of no exchange) ballast water were determined for 87 and 213 cases (one vessel may carry ballast water from several sources), respectively (Table 1). The most common sources of previous ballast water were Europe (28 vessels) and the Atlantic Ocean (12 vessels). The most common sources of current ballast water were the Atlantic Ocean (108 vessels), the Laurentian Channel (30 vessels), Montreal Harbour (20 vessels), and the St. Lawrence/Saguenay Rivers (18 vessels). Thus more than half of the ships entering the Seaway system carrying ballast likely to be discharged (108 of 212 vessels) carried ballast water from the Atlantic

Ocean at the time of entry to the Seaway, and an additional 68 vessels carried ballast water from fresh and estuarine sources connecting the Seaway and the Atlantic Ocean. No foreign freshwater ballast entered the Seaway in 1990, without having been at least partially exchanged. We conservatively estimate that at least 13 vessels would have entered the Seaway carrying freshwater ballast from European ports, if the GLBWCG were not in effect.

3.2.3. Volume of ballast water entering the Seaway

Extrapolating from the 411 foreign ocean-going vessels which reported their ballast status to the 455 vessels recorded in 1990, we estimate that 219 vessels entered the Seaway either fully or partially ballasted. Assuming a mean ballast water tonnage of 3,115 tonnes (based on 135 vessels) we calculate that 682,185 tonnes of ballast water were carried upbound in 1990 by vessels travelling fully or partially ballasted.

Foreign ocean-going vessels reporting 'no ballast water' probably carried, on average, 158 tonnes of 'unpumpable' ballast water (based on 7 vessels). Thus, an additional 37,288 tonnes was probably carried upbound by an estimated 236 vessels reporting no ballast water. We estimate that foreign ocean-going vessels carried at least 719,473 tonnes of ballast water into the Seaway in 1990.

Ballast water not in compliance with the guidelines, was carried by 21 upbound foreign ocean-going vessels [11% of ballasted vessels: (100 x 21)/177 + 21] which were known to be partially or fully ballasted. Extrapolating to the estimated 219 vessels carrying some ballast water, we estimate that 23 vessels carried high-risk ballast water; probably 73,924 tonnes (based on 49,004 tonnes known for 15 vessels and adding 3,115 tonnes on average for the remaining 8 vessels). To this we add high-risk water carried as 'unpumpable' ballast water. One vessel (3.6% of known 'unpumpable' ballast water) carried ballast water in this category, suggesting that 1,342 tonnes of 'unpumpable' water was carried. Combining these sources, at least 75,266 tonnes of risky ballast was probably carried upbound by foreign ocean-going vessels in 1990, representing 10 percent of the total volume carried upbound by ocean-going vessels in 1990.

Upbound lakers probably carried 2.5 times as much ballast water overall than the foreign ocean-going vessels. In 1990, 915 lakers travelled upbound (Table 2). Lakers and foreign ocean-going vessels are probably of similar average size because of physical size restrictions imposed by the locks, and consequently carry similar volumes of either ballast or cargo. More lakers travelled upbound in full ballast than foreign ocean-going vessels (30% and 24% respectively, based on SLSA records). Lakers upbound in the Seaway probably carried in excess of 1.8×10^6 tonnes of ballast water. In many cases this water originated from ports on the St. Lawrence River.

Foreign ocean-going vessels and lakers, combined, probably carried at least

Table 1. Known sources of previous (87) and current (213) ballast water in foreign ocean-going vessels entering the St. Lawrence Seaway.

Location	Previous	Current
Atlantic Ocean	12	108
Laurentian Channel	4	30
Montreal	4	20
St. Lawrence/Saguenay Rivers	1	18
Europe	28	7
Caribbean Sea	3	7
United States	9	6
Pacific Ocean	4	6
Canadian Maritime Ports	0	3
Mediterranean Sea	4	2
Asia	4	1
Baltic/North Sea,English Channel	3	1
Africa	3	1
Mexico/Cuba	2	1
Russia	2	1
Indian Ocean	0	1
Central/South America	2	0
Australia	1	0
Sea of Japan	1	0
TOTAL	87	213

2.5 x 10^6 tonnes of ballast water into the Seaway in 1990. Information received from the SLSA (Table 2) suggests that the volume of ballast water entering the Great Lakes has decreased in the past 5 years. The annual number of foreign vessels transiting the Seaway upbound over the last 5 years has decreased by 33 percent, although laker traffic has not changed. Mean vessel size has remained stable over this 5-year period, while the mean cargo tonnage/vessel has increased by 44 percent, suggesting that less ballast water is carried by each vessel.

3.2.4. Ballast water discharge and uptake in the St. Lawrence River

In total, 27 discharges of ballast water (including discharge of water preparatory to an exchange) were reported west of 64°W; 13 discharges in the St. Lawrence River and 14 in Montreal Harbour. Discharged water originated from the Atlantic Ocean (12 vessels), Laurentian Channel (2 vessels), North Sea (1 vessel), Portugal (1 vessel), Holland/France (1 vessel), Pacific Ocean (1 vessel), and Victoria River, Australia (1 vessel). It was not possible to determine the origin of water discharged by eight vessels. Six of the 27 vessels discharged water that was not in compliance with the GLBWCG and two more discharged water that should have been in compliance according to their reports, but salinity (between 20 and 30 °/oo) was not typical of seawater (> 30 °/oo), probably due to only partial exchange.

The relatively large number of vessels (38 of 213 vessels; Table 1) which took on ballast water in Montreal Harbour or the St. Lawrence/Saguenay Rivers suggests that ballast discharge by ships not complying with the GLBWCG should be prohibited in these areas.

Fresh water from the St. Lawrence River or river ports (Montreal, Quebec City, Sorel, and Contrecoeur) was carried upbound by 31 foreign ocean-going vessels. Based on an average volume of 1880 tonnes per vessel (23 vessels), we estimate that 31 vessels carried a total 43,251 tonnes of freshwater ballast upbound.

The volume of freshwater ballast carried upbound by lakers was less easily quantified. If 50 percent of the 1.8 x 10^6 tonnes carried by upbound lakers originated from freshwater ports on the river, this would represent 900,000 tonnes of freshwater ballast. Based on these estimates, foreign ocean-going vessels and lakers carried close to a million tonnes of fresh water from the St. Lawrence River upbound into the Seaway in 1990. We recommend that vessels not discharge any non-compliance ballast water west of 63°W longitude, the 1991 CCG western limit for exchange in the Laurentian Channel.

3.2.5. Ballast water discharge and uptake in the Laurentian Channel

Of 213 vessels for which the source of current ballast water could be determined,

Table 2. Vessel traffic in terms of total numbers, numbers in ballast, mean vessel size, and mean cargo tonnage for upbound vessels entering the St. Lawrence Seaway in the last 5 years. Ocean-going vessels include research vessels, tugs, cruiseships, and barges. Data derived from St. Lawrence Seaway Authority records.

Year	Number of vessels				Mean Vessel Size (tonnes)	Mean Cargo Tonnage /Vessel (tonnes)
	Ocean-going		Laker			
	Total	Ballast	Total	Ballast		
1990	474	112	915	278	12242	12704
1989	559	147	816	233	12646	12747
1988	619	82	957	362	12376	11838
1987	621	129	993	431	12493	10415
1986	704	-	959	-	1244	8807

30 had taken on or exchanged ballast in the Laurentian Channel (Table 1). Fifteen of these vessels reported previous ballast water; from American ports (4 vessels), Atlantic Ocean (2 vessels), North Sea (2 vessels), Mediterranean Sea (3 vessels), freshwater European ports (2 vessels) and Asia (2 vessels). According to the GLBWCG, ships should only exchange ballast water in the Laurentian Channel if they have not left the North American continental shelf, or in exceptional circumstances preventing offshore ballast water exchange. Only 4 vessels had not left the North American continental shelf, and the circumstances which prevented the other 11 vessels from completing an offshore exchange were not reported.

We suggest that the Laurentian Channel or an equivalent area continue to be available to upbound vessels as an alternate exchange site. Our data suggest that at least two ships might have entered the Seaway carrying ballast water originating from freshwater European ports if exchange in the Laurentian Channel had been prohibited.

One concern about ballast water exchange in the Laurentian Channel is that some vessels may not completely exchange ballast water in this area due to time constraints. Vessel captains reported to us that two to three days are required to completely exchange ballast water in a fully ballasted ship. The Laurentian Channel exchange area (61 to 63° W according to the 1991 GLBWCG) can be crossed by a vessel in less than a day. Vessels could easily reach freshwater parts of the St. Lawrence River (possibly even Montreal) before exchange was completed.

3.3. BOARDING AND SAMPLING VESSELS

Of the 98 vessels boarded, 62 were upbound in the Seaway, 2 were downbound, and 34 did not enter the Seaway. The 62 upbound vessels represent 13.6 percent of the upbound Seaway traffic.

Ballast water samples were taken from 59 vessels; 43 were upbound, 2 were downbound, and 14 did not enter the Seaway. We sampled 60.2 percent of all vessels boarded.

Samples could not be collected on 14 vessels which carried no ballast water, 11 of which had already discharged ballast water in Montreal Harbour or downstream in the St. Lawrence River. In one case, the captain of the vessel refused to allow a ballast water sample to be taken. On the 24 other vessels, it was not possible to sample either through a manhole cover or by a deck tap, or the history of the ballast water carried did not constitute a sampling priority. Samples could not be taken through a manhole cover if there was insufficient depth of ballast water for a vertical tow of the sampling nets, or the ballast water was carried in inaccessible ballast tanks (e.g. tanks which could only be accessed from inside another tank, or tanks whose manhole hatch could not be removed, most often because the manholes were beneath cargo or ship's stores).

Samples could not be taken by tap if the vessel was incapable of pumping from the ballast tanks to an accessible discharge tap, usually on deck or in the engine room. Water was pumped to a deck tap on 9 of the 59 vessels sampled, and the remainder were sampled by net hauls following removal of a manhole cover or other access hatch.

There were advantages and disadvantages associated with each of the sampling methods used in this study. Pumping via a deck tap permits sampling of a greater volume of water (Appendix F) and reduces the likelihood of damage to the plankton net, but there is a possibility of damage to soft-bodied organisms during transport through the pump. Mechanical damage to organisms is less likely to occur when they are sampled by vertical net tows within the ballast tank, but in order to avoid tearing the net on baffles or other projections in the tank, nets must be towed slowly and some planktonic organisms may be able to evade capture. As well, the baffles prevent good spatial coverage of much of the tank volume, and may permit pockets of organisms to remain undetected.

The volume of water sampled for zooplankton varied between ballast tanks (Appendix F). We observed no relationship between volume of water sampled and number of taxa identified in the samples, which suggests that the volume of water sampled was adequate to detect most species in the ballast tanks.

Sediments could be sampled only on vessels where ballast tanks were accessed through manhole covers. We had little success in sampling sediments. In many cases, baffles or other obstacles within the ballast tank prevented access to the sediments, and increased the possibilty of losing equipment that may become snagged. When sediments were visible from the hatch, they were often present as a thin layer (< 1 cm deep) located on a sloping and/or curved surface. An Ekman grab could not obtain a reasonable volume of sample under these conditions. It might have been possible to obtain samples using a submersible pump, but the variability of power sources on the vessels (which originated all over the world) meant that the two-person sampling team would have had to carry their own power source. This was not feasible given the other equipment carried by the sampling team.

3.4. BALLAST WATER HISTORIES OF THE SAMPLED VESSELS

The ships sampled were assigned to one of four categories based on their ballast water histories;

(1) ***Ships which did not exchange ballast water.*** Six ships had not exchanged any ballast water (Table 3). None of these ships carried freshwater ballast. However, brackish water reported as originating from the Straits of Florida near Havana was carried by one ship. The low salinity (23 °/oo) may indicate that freshwater ballast was previously carried, since the Caribbean Sea and adjacent waters are highly saline. The other five ships carried water of salinity ranging

from 35 to 39.5 °/oo. This water originated from Turkey, the Mediterranean Sea (two ships), Iceland and Pakistan.

(2) ***Ships which replaced freshwater ballast with freshwater or brackish ballast.*** Two of the sampled ships are of particular interest because ballast water originating from Rotterdam (a freshwater port) had been exchanged in freshwater or brackish regions of the St. Lawrence River. The ballast water carried by these two ships was of salinity < 10 °/oo.

(3) ***Ships which replaced freshwater ballast with saltwater ballast.*** Thirteen ships originating from freshwater ports had exchanged in seawater. The resultant salinities of < 10 °/oo (1 ship), 20 to 30 °/oo (3 ships) and > 30 °/oo (9 ships) suggest that the goal of fully replacing fresh water with salt water during exchange was not achieved in at least 4 vessels (32%).

(4) ***Ships which replaced saltwater ballast with saltwater ballast.*** The remaining 34 ships either originated from saltwater ports and exchanged water offshore, or took on saltwater ballast to a previously empty tank. Salinity of ballast water carried by these vessels ranged from 27 to 38 °/oo (Table 3). The vessel with ballast water of salinity 27 °/oo (GL 35; Table 3) took on water from the St. Lawrence River west of Les Escoumins. The low salinity probably indicates that freshwater residual water had been present in the ballast tank.

By examining salinity and biological data from vessels in these four categories, we are able to address the following questions;

(1) Does mid-ocean ballast exchange work? (i.e. does it increase salinity to typical oceanic salinities, usually > 30 °/oo; does it eliminate live freshwater organisms; does it eliminate dormant stages of freshwater organisms?)

(2) What are the salinity and biological characteristics of ballast water of ships that did NOT exchange?

(3) What are the effects of partial exchange on salinity and biotic composition?

(4) Do European freshwater organisms persist in the ballast tank of vessels that had exchanged in North American fresh waters?

(5) What is the effect of extensive de-ballasting of incoming vessels in Montreal Harbour? Have foreign organisms become established in the Harbour?

(6) What organisms are carried by ships that have taken on ballast water within the Seaway? Can these ships act as a vector, moving potential invaders from the lower St. Lawrence River or Montreal Harbour to the Great Lakes?

3.5. SALINITY

Salinities reported in BWERs (as specific gravity) should not be used as a preliminary measure of compliance. Conversion of specific gravity to salinity can be

Table 3. Summary of sampled ships, by ballast water exchange characteristics.

Sample Code	Vessel Name	Salinity °/oo	Previous Ballast Water	Current Ballast Water
A. No exchange				
GL13	Singa Saga	39.5	None	Turkey
GL16	Solin	39	None	Mediterranean Sea
GL20	Sandnes	35	None	Stramsvik
GL36	Khairpur	37	None	Karachi
GL41	Sibanimar	23	None	Straits of Fla. near Havana
GL43	Pontoporos	38.5	None	Med. Sea near Libya
B. Originated from freshwater port, exchanged in freshwater/estuarine				
GL21	Stolt Castle	3,9	Gibraltar & Rotterdam	N.E. Atl., topped up in St. Lawr. R., E. of Quebec City
GL57	Nordic	4	Rotterdam	St. Lawrence R. E. of Montreal
C. Originated from freshwater port, exchanged in salt water				
GL3	Ziemia Chelminska	21	Montoir	Mid N. Atlantic
GL7	Malinska	33	Antwerp	Mid N. Atlantic
GL23	Korean Trader	29	Camden (N.J.)	N.W. Atlantic, topped up in Laurentian Channel
GL26	Thor I	37	Montreal Harbour	N. Atlantic
GL32	Miss Aliki	22	Newark (N.J.)	N.W. Atlantic
GL34	Alexandria	34	Rotterdam	E. & Mid N. Atlantic
GL44	Thor I	37	St. Lawrence R.	N.W. & S.E. Atlantic & Gr. Lakes
GL48	Selkirk Settler	32	Ghent	N.E. Atlantic
GL49	Green Laker	31	Philadelphia	Laurentian Channel
GL51	Fulvia	36	Panama Lake	Caribbean Sea
GL56	Thorscape	24	L. Ontario or Montreal	S.E. & Mid N. Atlantic
GL58	Proof Trader	36	Toronto	N.W. Atlantic
D. Originated from saltwater port (or no previous ballast water) and exchanged in salt water				
GL1	Bohinj 2	34	Bishop Rock (near England)	Mid N. Atlantic

Table 3 (Continued)

Sample Code	Vessel Name	Salinity ‰	Previous Ballast Water	Current Ballast Water
GL2	Anangel Prosperity	34	Le Havre	Mid N. Atlantic
GL4	Al Samad	38	Algeria	Cabot Strait
GL5	Anangel Horizon	37	Mediterranean near Gibraltar	N.E. Atlantic
GL8	Orient Star	34	Tarragona	Laurentian Channel
GL9	Sun Ocean	36	Carib. Sea & N.W. Atlantic	Laurentian Channel
GL10	Golden Crown	36	Venezuela	N.W. Atlantic near Bermuda
GL11	Khudozhnik Prorokov	37	N. Atlantic	Mid N. Atlantic
GL12	Aleksandr Starostenko	34	North Sea	Mid N. Atlantic
GL14	Kavo Yerakas	35	North Sea	Mid N. Atlantic
GL15	Korali	38	Algiers	Mid N. Atlantic
GL17	Furunes	35	Finland	Mid N. Atlantic
GL18	Leo M	37	Pasajes	N.E. Atlantic
GL19	Ionian Express	36	E. coast of South Africa	N.W. Atlantic
GL22	Anatoliy Lyapidevskiy	37	North Sea	N.W. Atlantic
GL24	Aleksandr Starostenko	35	N. Atlantic	Mid N. Atlantic
GL25	Consensus Sea	35	Caribbean Sea	N.W. Atlantic
GL27	Kallio	35	Pasajes	Mid N. Atlantic
GL28	Federal Saguenay	31	Huelva	Mid N. Atlantic
GL29	Canmar Venture	36	Mediterranean Sea ports	Mid N. Atlantic
GL30	Saint Laurent	32	Tokyo Bay	N.E. Pacific
GL31	Socrates	33	New Haven (Conn.)	Laurentian Channel
GL33	San Lorenzo	37	Cadiz	N.E. Atlantic
GL35	Berta Dan	27	None	St.Lawr R. (W. of Les Escoumins)
GL37	Khudozhnik Prorokov	36	Mid N. Atlantic (+ Europe?)	Mid N. Atlantic
GL38	Kallio	37	Pasajes	E. to Mid N. Atlantic
GL39	Babor	37	Algiers	Mid N. Atlantic
GL42	Skaw Trader	32	None	Med. Sea & Mid N. Atlantic
GL45	Pamisos	37	None	Mid N. Atlantic
GL46	Federal Saguenay	31	None	St. Lawr. R. (E. of Quebec City)

Table 3 (continued)

Sample Code	Vessel Name	Sali-nity °/oo	Previous Ballast Water	Current Ballast Water
GL47	Leo M	37	Pasajes	N.E. Atlantic
GL50	Sir John	37	Manfredonia	N.W. Atlantic
GL52	Kallio	36	Pasajes	N.E. Atllantic
GL53	Project Carrier	33	Sea of Japan	N.E. Pacific
GL59	Leo M	38	Pasajes	E. to Mid N. Atlantic
E. Originated in Montreal Harbour or Great Lakes				
GL6	Norman Sirina	0	None	Montreal Harbour
GL40	Kavo Yerakas	0	None	Montreal Harbour
GL54	Helena Oldendorff	2	Sable Island, Chicago	Hamilton
GL55	Ais Mamas	1	None	Thorold

Table 4. Salinity measured by refractometer on sampled vessels, or calculated from specific gravity, (*= estimated t°C).

Vessel/Sample Code	Date M,D	Specific Gravity	t°C	Salinity °/oo Calculated	Measured
Gerdt Oldendorff	4 11	1.025	5 *	31.6	--
La Richardais	4 19	1.015,1.025	5 *	18.9, 31.6	--
Shimone	5 24	1.026	16 *	35.3	--
Fairnes	5 25	1.025	16 *	34.0	--
Suntempest	5 25	1.010	16 *	14.4	--
Istrian Express	5 28	1.025	16 *	34.0	--
Bohinj 2 (GL 1)	5 29	--	16	--	34
Lok Prem	6 4	1.025	16 *	34.0	--
Anangel Prosperity (GL 2)	6 6	1.021	16 *	28.8	34
Gur Master	6 6	1.025	16 *	34.0	--
Gogo Chemstar	6 9	1.000	16 *	<1.8	--
Lara S	6 10	1.025	16 *	34.0	--
Ziemia Chelminska (GL 3)	6 13	--	17	--	20
Al Samad (GL 4)	6 14	1.025	16	34.0	38
Lux Challenger	6 17	1.025	17 *	34.3	--
Anangel Horizon (GL 5)	6 18	--	18	--	37
Norman Sirina (GL 6)	6 21	--	17	--	0
Malinska (GL 7)	6 21	--	16	--	33
Hoko Nova	6 25	1.025	16 *	34.0	--
Orient Star (GL 8)	6 29	--	15	--	34
Firat	6 30	1.025	15 *	33.7	--
Sun Ocean (GL 9)	7 3	--	20	--	36
Golden Crown (GL 10)	7 5	--	20	--	36
Aquarius	7 6	1.000	21 *	2.6	--
Sunbrisa	7 9	1.025	21 *	35.6	--
Khudozhnik Prorokov (GL11)	7 10	--	22	--	37
Aleksandr Starostenko (GL12)	7 12	--	19	--	34
Orient Sun	7 15	1.024	21 *	34.3	--
Akmi	7 15	1.000	21 *	2.6	--
Sun Stinnes	7 18	1.025	22 *	36.0	--
Singa Saga (GL 13)	7 18	--	22	--	39.5
Argus	7 22	1.025	21 *	35.6	--
Thorscape	7 26	1.000	20	2.3	--
Kavo Yerakas (GL 14)	7 27	1.023	20 *	32.7	35

Table 4 (Continued)

Vessel/Sample Code	Date M,D	Specific Gravity	t°C	Salinity °/oo Calculated	Measured
Korali (GL 15)	7 31	–	20	–	38
Solin (GL 16)	8 1	–	22	–	39
Caribbean Princess	8 1	1.015	22 *	22.8	–
Furunes (GL 17)	8 2	1.025	22	36.0	35
Arktis Pearl	8 3	1.025	21 *	35.6	–
Leo M (GL 18)	8 7	–	19.5	–	37
Ionian Express (GL 19)	8 9	–	22	–	36
Sandnes (GL 20)	8 9	–	15	–	35
Stolt Castle (GL 21)	8 14	–	26,21.5	1,4	3,9
Anatoliy Lyapidevskiy (GL22)	8 21	1.026	20	36.6	37
Korean Trader (GL 23)	8 22	1.025	20	35.3	29
Aleksandr Starostenko (GL 24)	8 23	–	18	–	35
Consensus Sea (GL 25)	8 23	–	25	–	35
Thor I (GL 26)	8 24	–	23	–	37
Kallio (GL 27)	8 27	–	20	–	35
Federal Saguenay (GL 28)	8 31	–	19.5	–	31
Omisalj	9 3	1.025,1.020	20 *	35.3,28.7	–
Canmar Venture (GL 29)	9 7	–	21	–	36
Saint Laurent (GL 30)	9 12	–	14	–	32
Mehmet Emin	9 13	1.011	14 *	15.2	–
Socrates (GL 31)	9 17	–	14	–	33
Miss Aliki (GL 32)	9 18	1.003	19	5.6	22
San Lorenzo (GL 33)	9 20	–	14	–	33
Alexandria (GL 34)	9 23	–	13	–	34
Berta Dan (GL 35)	9 23	–	16	–	27
Mizoram	9 23	1.025	16 *	34.0	–
Mountain Blossom	9 23	1.025	16 *	34.0	–
Khairpur (GL 36)	9 24	–	17	–	37
Conti Blue	9 27	1.025	16 *	34.0	–
Khudozhnik Prorokov (GL37)	10 1	–	15	–	36
Kallio (GL 38)	10 2	–	12	–	37
Thorscape	10 3	1.025	12 *	32.9	–
Sagittarius	10 7	1.025	12 *	32.9	–
Babor (GL 39)	10 11	–	12	–	37

Table 4 (Continued)

Vessel/Sample Code	Date M,D	Specific Gravity	t°C	Salinity °/oo Calculated	Salinity °/oo Measured
Kavo Yerakas (GL 40)	10 12	--	13.5	--	0
Sibanimar (GL 41)	10 12	1.023	13	30.6	23
Skaw Trader (GL 42)	10 14	1.025	14	33.4	32
Kupari	10 17	1.025	15 *	33.7	--
Pontoporos (GL 43)	10 18	--	16.5	--	38.5
Ikan Sepat	10 20	1.025	13 *	33.2	--
Thor I (GL 44)	10 22	--	11	--	37
Pamisos (GL 45)	10 23	1.026	9	33.5	37
Federal Saguenay (GL 46)	10 24	--	9	--	31
Nordic	10 29	1.025	9 *	32.3	--
Selkirk Settler	10 30	--	9 *	--	32
Leo M (GL 47)	10 31	--	9	--	37
Selkirk Settler (GL 48)	11 1	--	7.5	--	32
Green Laker (GL 49)	11 1	--	7	--	31
Sir John (GL 50)	11 5	--	6.5	--	37
Fulvia (GL 51)	11 12	--	4.5	--	36
State of Manipur	11 15	1.025	4 *	31.5	--
Kallio (GL 52)	11 20	--	3	--	36
Kamtin	11 20	1.025	3 *	31.3	--
Bahia De Manzanillo	11 21	1.024	8 *	30.8	--
Project Carrier (GL 53)	11 21	1.025	8	32.1	33
Baronia	11 22	1.025	10 *	32.5	--
Helena Oldendorff (GL 54)	11 24	--	10	--	2
Darya Kamal	11 24	1.025	9 *	32.3	--
Ais Mamas (GL 55)	11 27	--	7	--	1
Thorscape (GL 56)	12 4	1.025	4	31.5	24
Nordic (GL 57)	12 4	--	5	--	4
Proof Trader (GL 58)	12 6	--	1	--	36
Leo M (GL 59)	12 6	--	1	--	38

Table 5. Summary of sampled ships based on measured salinity.

Sample Code	Vessel Name	Salinity °/oo	Previous Ballast Water	Current Ballast Water
			A. Low salinity (< 10 °/oo)	
GL 6	Norman Sirina	0	None	Montreal Harbour
GL 40	Kavo Yerakas	0	None	Montreal Harbour
GL 54	Helena Oldendorff	2	Sable Island, Chicago	Hamilton
GL 55	Ais Mamas	1	None	Thorold
GL 21	Stolt Castle	3,9	Gibraltar & Rotterdam	N.E. Atl., topped up in St. Lawr. R., E. of Quebec City
GL 57	Nordic	4	Rotterdam	St. Lawrence R., E. of Montreal
			B. Intermediate salinity (20-30 °/oo)	
GL 3	Ziemia Chelminska	21	Montoir	Mid N. Atlantic
GL 23	Korean Trader	29	Camden (N.J.)	N.W. Atlantic, topped up in Laurentian Channel
GL 32	Miss Aliki	22	Newark (N.J.)	N.W. Atlantic
GL 35	Berta Dan	27	None	St. L. R. (W. of Les Escoumins)
GL 41	Sibanimar	23	None	Straits of Fla. near Havana
GL 56	Thorscape	24	L. Ontario or Montreal	S.E. & Mid N. Atlantic
			C. High salinity (> 30 °/oo)	
GL 1	Bohinj 2	34	Bishop Rock (near England)	Mid N. Atlantic
GL 2	Anangel Prosperity	34	Le Havre	Mid N. Atlantic
GL 4	Al Samad	38	Algeria	Cabot Strait
GL 5	Anangel Horizon	37	Mediterranean near Gibraltar	N.E. Atlantic
GL 7	Malinska	33	Antwerp	Mid N. Atlantic
GL 8	Orient Star	34	Tarragona	Laurentian Channel
GL 9	Sun Ocean	36	Carib. Sea & N.W. Atlantic	Laurentian Channel
GL 10	Golden Crown	36	Venezuela	N.W. Atlantic near Bermuda
GL 11	Khudozhnik Prorokov	37	N. Atlantic	Mid N. Atlantic

Table 5 (Continued)

Sample Code	Vessel Name	Salinity °/oo	Previous Ballast Water	Current Ballast Water
GL 12	Aleksandr Starostenko	34	North Sea	Mid N. Atlantic
GL 13	Singa Saga	39.5	None	Turkey
GL 14	Kavo Yerakas	35	North Sea	Mid N. Atlantic
GL 15	Korali	38	Algiers	Mid N. Atlantic
GL 16	Solin	39	None	Mediterranean Sea
GL 17	Furunes	35	Finland	Mid N. Atlantic
GL 18	Leo M	37	Pasajes	N.E. Atlantic
GL 19	Ionian Express	36	E. coast of S. Africa	N.W. Atlantic
GL 20	Sandnes	35	None	Stramsvik
GL 22	Anatoliy Lyapidevskiy	37	North Sea	N.W. Atlantic
GL 24	Aleksandr Starostenko	35	N. Atlantic	Mid N. Atlantic
GL 25	Consensus Sea	35	Caribbean Sea	N.W. Atlantic
GL 26	Thor I	37	Montreal Harbour	N. Atlantic
GL 27	Kallio	35	Pasajes	Mid N. Atlantic
GL 28	Federal Saguenay	31	Huelva	Mid N. Atlantic
GL 29	Canmar Venture	36	Mediterranean Sea ports	Mid N. Atlantic
GL 30	Saint Laurent	32	Tokyo Bay	N.E. Pacific
GL 31	Socrates	33	New Haven (Conn.)	Laurentian Channel
GL 33	San Lorenzo	37	Cadiz	N.E. Atlantic
GL 34	Alexandria	34	Rotterdam	E. & Mid N. Atlantic
GL 36	Khairpur	37	None	Karachi
GL 37	Khudozhnik Prorokov	36	Mid N. Atl.(+ Europe?)	Mid N. Atlantic
GL 38	Kallio	37	Pasajes	E. to Mid N. Atlantic
GL 39	Babor	37	Algiers	Mid N. Atlantic
GL 42	Skaw Trader	32	None	Med. Sea & Mid N. Atlantic
GL 43	Pontoporos	38.5	None	Med. Sea near Libya
GL 44	Thor I	37	St. Lawr. R. & Great Lakes	N.W. & S.E. Atlantic
GL 45	Pamisos	37	None	Mid N. Atlantic
GL 46	Federal Saguenay	31	None	St. Lawr. R. (E. of Quebec City)

Table 5 (continued)

Sample Code	Vessel Name	Salinity °/oo	Previous Ballast Water	Current Ballast Water
GL 47	Leo M	37	Pasajes	N.E. Atlantic
GL 48	Selkirk Settler	32	Ghent	N.E. Atlantic
GL 49	Green Laker	31	Philadelphia	Laurentian Channel
GL 50	Sir John	37	Manfredonia	N.W. Atlantic
GL 51	Fulvia	36	Panama Lake	Caribbean Sea
GL 52	Kallio	36	Pasajes	N.E. Atlantic
GL 53	Project Carrier	33	Sea of Japan	N.E. Pacific
GL 58	Proof Trader	36	Toronto	N.W. Atlantic
GL 59	Leo M	38	Pasajes	E. to Mid N. Atlantic

accomplished using known relationships of water density, salinity, and temperature. Since temperature is not reported in the BWER, the necessary salinity calculations must be based on estimates of temperature at the time that specific gravity was recorded. Even in cases where the vessel had been boarded and the temperature measured, there is no guarantee that the temperature had not changed since the specific gravity measurement was made. Consequently, our salinity computations based on reported specific gravity are highly suspect. When comparisons with refractometer readings were possible, the two measures of salinity differed by as much as 7.5 °/oo (Table 4). We suggest that in order to obtain reliable measures of salinity for ballast water monitoring, a refractometer, conductivity meter or similar on-site test should be used.

Among the 59 ships from which we obtained salinity readings by refractometer, six ships contained ballast water of salinity < 10 °/oo (Table 5). These included the two downbound vessels sampled (ballast water from Hamilton and Thorold, respectively), two ships which took on ballast in Montreal Harbour, and two ships from Rotterdam which had partially exchanged their ballast water in the St. Lawrence River.

Six more ships carried brackish ballast water of salinity between 20 and 30 °/oo. Four of these ships had only partially exchanged ballast water, one ship entering Canadian waters without ballast had taken on water in the St. Lawrence estuary, and one ship had not exchanged ballast water originating from the Straits of Florida near Havana.

The remaining 47 ships carried ballast water of salinity > 30 °/oo. Five of these vessels had not exchanged ballast water (but had originated from saltwater ports).

In most cases the salinities corroborated the reported ballast exchange history of the vessels. For example, the three vessels reporting ballast water from the Mediterranean Sea had salinities of 38.5 to 39.5 °/oo (Table 5), comparable to typical salinities for the area of 37 to 39 °/oo (Kinne, 1963). Two vessels reporting ballast exchange in the Pacific carried water of 32 and 33 °/oo (Table 5), similar to mean salinity of 33.7 °/oo in the North Pacific (Kinne, 1963). The 38 vessels reporting ballast exchange in the North Atlantic contained waters ranging in salinity from 31 to 38 °/oo (Table 5); however, the North Atlantic is recorded as having a relatively invariant salinity with mean 35.3 °/oo (Kinne, 1963), so probably these values indicate mixtures of Atlantic Ocean water with previous ballast water of different salinity. For example, most of the vessels with above-average salinities had previously carried ballast water from the Mediterranean, which has higher salinity than the Atlantic Ocean.

Four vessels with salinities below 30 °/oo reported exchanging ballast water in the Atlantic. All four vessels reported previous (pre-exchange) ballast water from freshwater ports, so it is likely that these ships only completed a partial exchange.

3.6. PICOPLANKTON

Autotrophic picoplankton could not be used as an indicator of ballast water status because they were present only at very low levels, frequently below detection

limits (Appendix E). The absence of autotrophic picoplankton is attributed to poor conditions for their survival in ballast tanks, e.g. lack of light or nutrients.

Heterotrophic picoplankton (bacteria) were present at concentrations up to 1.923 x 10^6 ml^{-1} (Appendix E). Abundance decreased with increasing salinity, although the relationship is not strong. We feel that use of a refractometer alone for salinity determination is adequate.

3.7. ZOOPLANKTON

3.7.1. Zooplankton in ballast water

Zooplankton belonging to 12 phyla were collected from ballast tanks (Table 6). Most samples were numerically dominated by copepods, cladocerans, or rotifers (Appendix K, L). Virtually all ballast tanks sampled (88%) contained live zooplankton on arrival at Montreal.

Zooplankton collected from unexchanged ballast water or exchanged ballast water which originated from a freshwater port (Appendix K) were categorized according to their ability to invade fresh waters (Table 7). The organisms considered capable of survival and reproduction in fresh waters included representatives of Rotifera, Acarina, Cladocera, and Copepoda. The Rotifera are primarily freshwater although numerous genera typical of fresh waters are also found in marine or estuarine environments (Thane-Fenchel, 1968). Because of the difficulty of differentiating marine and freshwater species within these genera, we considered all rotifers to be potential invaders of fresh waters. The representatives of Acarina families Pionidae and Aturidae which we observed were freshwater taxa (H. Proctor, University of Toronto, personal communication). Likewise, the cladoceran families Daphnidae, Sididae, Bosminidae, and Chydoridae are found primarily in fresh water although some estuarine populations of *Bosmina* exist. Copepods considered likely to survive and reproduce in fresh water included typically freshwater calanoids (the genera *Leptodiaptomus*, *Skistodiaptomus*, *Limnocalanus*, *Epischura*), cyclopoids (*Macrocyclops*, *Diacyclops*, *Mesocyclops*, *Tropocyclops*, *Cyclops*) and a harpacticoid (*Bryocampus*). The estuarine calanoid *Eurytemora affinis* (Poppe) was also included among potential invaders due to its demonstrated ability to survive in fresh waters, including the Great Lakes (Faber & Jermolajev, 1966).

Live zooplankton of freshwater taxa occurred mainly in the four ships that had ballasted within the St. Lawrence - Great Lakes system (Montreal Harbour,

Table 6. List of zooplankton taxa collected from ballast tanks (BT) or Montreal Harbour (MH).

Taxa	BT	MH
CNIDARIA		
Hydrozoa		
medusae	x	
polyps		x
colonies	x	
PLATYHELMINTHES		
Turbellaria	x	
ROTIFERA		
Keratella sp.	x	x
Kellicottia longispina (Kellicott)		x
Polyarthra remata (Skorikow)	x	x
Synchaeta sp.	x	
Polyarthra sp.	x	
Asplanchna sp.	x	
Brachionus sp.	x	
Lecane sp.	x	x
Euchlanis sp.	x	x
Trichocerca sp.	x	
NEMATODA	x	x
ANNELIDA		
Polychaeta		
Phyllodocidae		
Etione sp. metatrochophore	x	
Anaitides sp. nectochaete	x	
?Phyllodoce sp. nectochaete	x	
Spionidae		
"Polydora complex" metatrochophore	x	
Spiophanes sp. metatrochophore	x	
Oligochaeta		
Aeolosoma sp.		x
Chaetogaster diaphanus (Gruithuisen)		x
Chaetogaster diastrophus (Gruithuisen)		x
Chaetogaster limnaei K. von Baer	x	
Chaetogaster setosus Svetlov		x

Table 6 (continued)

Taxa	BT	MH	
?Chaetogaster sp.		x	
Bero ?nivea Aiyer		x	
Nais behningi Michaelsen		x	
Nais communis Piguet		x	
Nais ?elinguis O.F. Müller	x		
Nais simplex Piguet	x		
Naididae fragments		x	
MOLLUSCA			
Gastropoda (veligers)	x		
Prosobranchia	x		
Opisthobranchia	x		
Bivalvia (veligers)		x	
ACARINA			
Pionidae		x	
unidentified nymph	x		
Forelia sp.	x		
Aturidae			
Aturus sp.		x	
Monostigmata			
unidentified terrestrial species	x		
CLADOCERA			
Bosminidae			
Bosmina coregoni (Baird)	x	x	
Bosmina longirostris (O.F. Müller)		x	x
Bosmina longispina (Leydig)	x		
Bosmina sp.	x	x	
Daphnidae			
Moina sp.		x	
Daphnia longispina (O.F. Müller)	x		
Daphnia retrocurva Forbes	x		
Daphnia galeata mendotae Birge	x		
Daphnia sp.	x	x	
Ceriodaphnia quadrangula (O.F. Müller)	x		
Ceriodaphnia sp.	x		
Sididae			
Diaphanosoma sp.		x	

Table 6 (continued)

Taxa	BT	MH
Chydoridae		
Chydorus sp. (sphaericus group)	x	x
Chydorus brevilabri Frey	x	x
Alona costata Sars		x
Alona affinis Leydig	x	
Graptoleberis testudinaria (Fischer)	x	x
Pseudochydorus globosus (Baird)	x	
Pleuroxus denticulatus Birge	x	
Camptocercus rectirostris Schødler	x	
Camptocercus sp.		x
Polyphemidae		
Podon polyphemoides Leuckart	x	
OSTRACODA		
Podocopa	x	x
COPEPODA		
Calanoida		
Diaptomus sp.	x	
Leptodiaptomus minutus Lilljeborg	x	
Leptodiaptomus ashlandi Marsh	x	
Skistodiaptomus oregonensis Lilljeborg	x	
Limnocalanus macrurus Sars	x	
Epischura lacustris S.A. Forbes	x	
Eurytemora affinis (Poppe)	x	x
Centropages typicus Krøyer	x	
Centropages velificatus (de Oliviera)	x	
Temora longicornis (O.F.Müller)	x	
Temora turbinata (Dana)	x	
Temora sp.	x	
Calanus finmarchicus (Gunner)	x	
Calanus sp.	x	
Acartia clausi Giesbrecht	x	
Euchaeta norvegica (Boeck)	x	
unidentified species	x	
Cyclopoida		
Macrocyclops albidus (Jurine)		x

Table 6 (continued)

Taxa	BT	MH
Diacyclops thomasi S.A. Forbes	x	
Mesocyclops edax (S.A. Forbes)	x	
Tropocyclops prasinus (Fischer)	x	x
Cyclops sp.	x	
Oithona similis Claus	x	
Oithona sp.	x	
unidentified species	x	x
Harpacticoida		
Microsetella norvegica (Boeck)	x	
Parathalestris croni (Krøyer)		x
Bryocampus sp.	x	
unidentified species	x	x
CIRRIPEDIA		
nauplii	x	
cypris larvae	x	
MYSIDACEA	x	
ISOPODA		
Dajidae (cryptoniscid stage-parasitic on barnacles)	x	
AMPHIPODA		
Hyperiidea (embryonic stages prematurely released)	x	
Gammaridea		
Gammarus ?tigrinus Sexton (subadult)	x	
Gammarus sp. (immature)	x	x
EUPHAUSIACEA		
nauplius	x	
protozoea	x	
DECAPODA (zoea, megalopa)		
Caridea	x	
Brachyura	x	
INSECTA		
Coleoptera	x	
Diptera (Chironomidae larva)	x	x

Table 6 (continued)

Taxa	BT	MH
TARDIGRADA	x	
BRYOZOA (cyphonautes larva)	x	
ECHINODERMATA (ophiopluteus larva)	x	
CHAETOGNATHA	x	
CHORDATA Larvacea (?)		x

Table 7. Summary of zooplankton data by salinity tolerances. (x = live when collected, o = dead when collected).

Origin	Rotifera	Oligochaeta	Acarina	Bosminidae	Daphnidae	Sididae	Chydoridae	Calanoida	Cyclopoida	Harpacticoida	Polychaeta	Gastropoda	Bivalvia	Polyphemidae	Calanoida	Cyclopoida	Harpacticoida	Cirripedia	Isopoda	Euphausiacea	Bryozoa	Echinodermata	Larvacea	Amphipoda	Hydrozoa	Turbellaria	Nematoda	Ostracoda	Calanoida	Cyclopoida	Harpacticoida	Mysidacea	Amphipoda	Insecta
SURVIVE IN FRESH WATER											**RESTRICTED TO SALT WATER**														**SALINITY TOLERANCES UNCERTAIN**									
Montreal Harbour:																																		
MH 1-4	x	x	o	x	o	o	o	x	x	x	o												o											
Ballasted in the St. Lawrence/Great Lakes system																																		
GL-6	x	o	o	x	o		o	x	x	x													o			x	o							
GL-40	x	x		x			x	x	x	o															x	o								
GL-54	x		x	x	x		x	x	x	o															x	o								
GL-55	o			x	x		x	x	x	o																								
Originated in fresh water, exchanged in fresh water																																		
GL-21	o	o																																
GL-57	o		o				x																											
Originate in fresh water, exchanged in salt water																																		
GL-3	o	o	o	o		o		o			o					x	x								o								
GL-7	o		o									x				x	x									x								
GL-23			o										x			x																		
GL-26			o									x	x			x																		
GL-32																																		
GL-34																																		
GL-44	x																																	
GL-48	x																																	
GL-49	x																																	
GL-51																																		
GL-56	o		o																															
GL-58			o																															
Originated in salt water, no exchange																																		
GL-13	o		o																															
GL-16	o		o																															
GL-20		x									x	x					o		o					x		x								
GL-36	o		o								x	x	x													x		o	o	o		x		
GL-41	o		o										x																	o				
GL-43	o																																	

Hamilton, and Thorold; Table 7). However, live rotifers were found in ballast water of three ships which originated in freshwater ports and exchanged ballast offshore (salinities 31 to 34 °/oo). Similarly, live *E. affinis* were collected from a vessel which had originated in Rotterdam and exchanged ballast in the St. Lawrence River (salinity 4 °/oo) and from a vessel which had originated in Antwerp and exchanged ballast in the mid-Atlantic Ocean (salinity 33 °/oo). Although the absence of live freshwater zooplankton from most saltwater ballast samples indicates ballast exchange to be very useful, their presence in a few cases indicates exchange to be less than 100 percent effective. We calculated effectiveness of ballast exchange using ships originating in foreign freshwater ports and exchanging ballast water in mid-ocean (12 vessels; Table 7). Four vessels (33%) carried zooplankton that could live in the Great Lakes. Thus effectiveness of ballast water exchange was 67 percent.

The lack of live freshwater zooplankton (except for *E. affinis*) in the two samples from vessels that had originated in Rotterdam and exchanged ballast in the St. Lawrence River is probably due to two factors. The ballast tanks of vessel GL-21 had been coated with a substance called 'Corrolana' (manufacturers and composition unknown to us) which was apparently toxic, since the sample contained no live zooplankton. The second vessel, GL-57, was sampled in December, when many freshwater zooplankters are in inactive overwintering stages and therefore are not found in the water column where they may be entrained in a ships ballast water intake.

We were unable to unequivocally demonstrate the presence of foreign freshwater zooplankton in this study. Taxa identified in this study, including *E. affinis*, cladocerans and rotifers are found in both Europe and North America. Currently, taxonomic literature considers many zooplankton taxa to be cosmopolitan, although recent taxonomic revisions have begun to differentiate North American and European species (e.g. Frey, 1986, 1987).

Dead freshwater specimens were present in almost all ships, including those which had originated from a saltwater port and had exchanged ballast water in salt water (Appendix L). Presumably these freshwater organisms originated in unpumpable residual water from a previous port. The presence of freshwater 'remnants' in ballast tanks is of concern because it suggests that dormant stages of these organisms may also remain in the bottom of the ballast tanks. If this is the case, any ship which has ever taken on ballast in a freshwater port may pose a risk to the Great Lakes ecosystem, even if it complies with the ballast exchange guidelines. Salinity tolerances of dormant stages of freshwater organisms are largely unknown, but dormant zooplankton are usually resistant to a wide range of environmental stresses (Section 4). An experimental bioassay of salinity tolerance of dormant stages of a range of freshwater organisms would provide a means of assessing the risk involved in transport of sediment in ship's ballast tanks. Our attempts to culture planktonic organisms from sediment collected in ballast tanks were unsuccessful, but this does not rule out the

possibility that viable stages were present in the sediments.

3.7.2. Geographic variations in ballast tank zooplankton

Taxonomic composition of live organisms collected in zooplankton samples was compatible with the reported place of origin of the ballast water. For reasons outlined in Section 3.7.1., it was not possible to differentiate North American and European species. However, latitudinal differences in zooplankton composition were apparent in the samples. For example, Caribbean copepods (e.g. *Temora turbinata*, *Centropages velificatus*) were found only in ballast water from the Caribbean (vessel GL-41), whereas different representatives of the genera (*Temora longicornis*, *Centropages typicus*) were found in ballast water taken on in the North Atlantic.

At higher taxonomic levels, limited geographic variability was observed. Live Cladocera were found only in samples from the Great Lakes or St. Lawrence River (Figure 2). Live Turbellaria, Cirripedia, Mysidacea, Isopoda, Amphipoda, Decapoda, Tardigrada, and Bryozoa were found only in samples from the Atlantic Ocean. Ostracoda were collected only in samples from the Laurentian Channel. No Nematoda were found in samples from the Pacific Ocean, and no Calanoida in the Mediterranean Sea. Only Cyclopoida were found in all geographic regions.

3.7.3. Seasonal variations in zooplankton in saltwater ballast

Investigation of seasonal variations is based primarily on zooplankton collected from vessels carrying saltwater ballast since this was the only ballast water type represented in sufficient numbers. Live Hydrozoa, Turbellaria, Isopoda, Bryozoa, Echinodermata, Chaetognatha, and Tardigrada were collected in autumn only (Figure 3). Live Ostracoda, Gammaridea, and Decapoda were present only in summer samples. Nematoda, Calanoida, Cyclopoida and Harpacticoida were found fairly consistently throughout the sampling season. Rotifera, Polychaeta, Gastropoda, Bivalvia, and Cirripedia were collected sporadically throughout the season. Mysidacea were collected in June and October only.

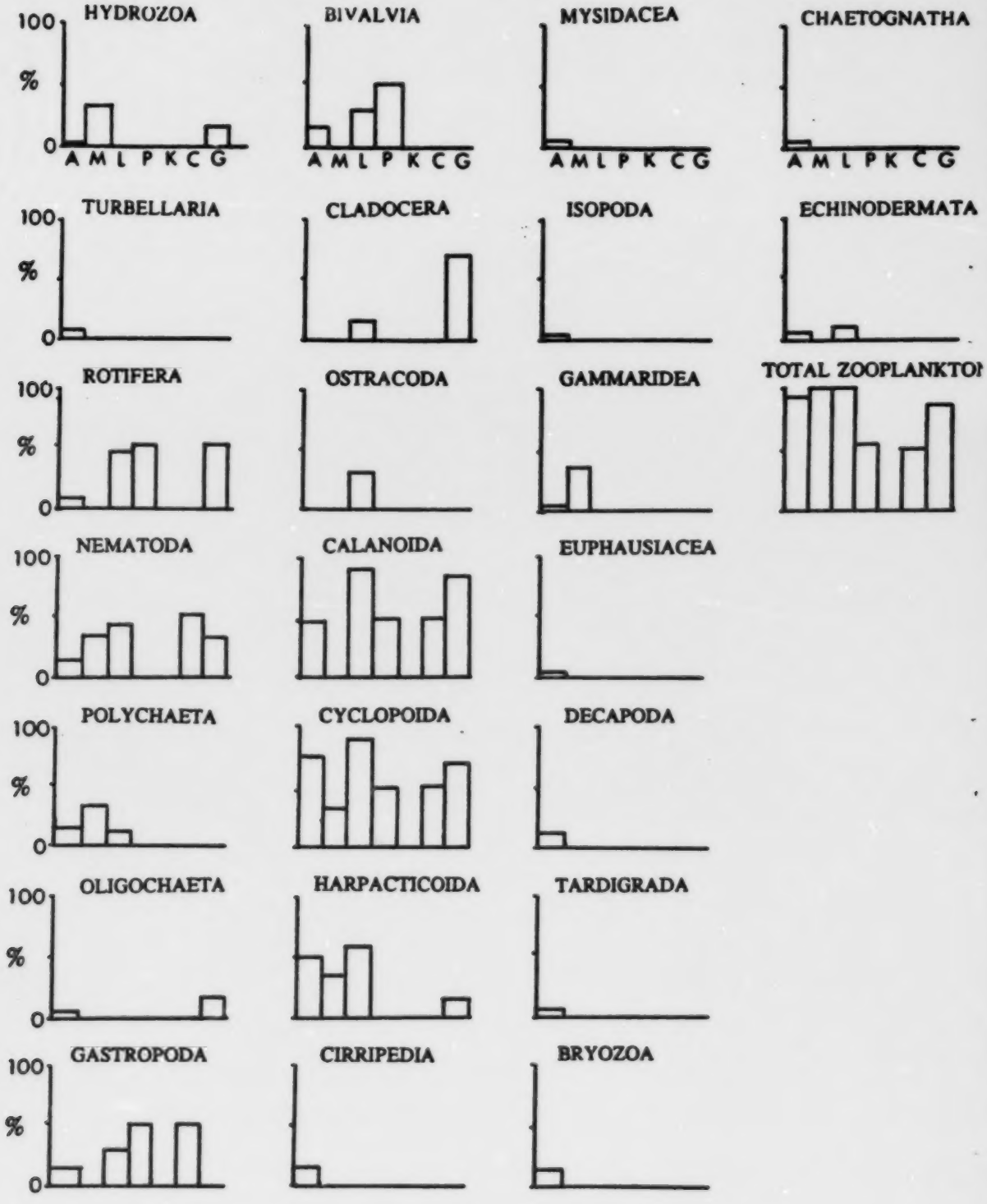

Figure 2. Geographic variation in percent of ballast water samples containing live zooplankton. (A = Atlantic, n = 39; M = Mediterranean, n = 3; L = Laurentian Channel, n = 6; P = Pacific, n = 2; K = Karachi, Pakistan, n = 1; C = Caribbean, n = 2; G = Great Lakes or St. Lawrence River, n = 6).

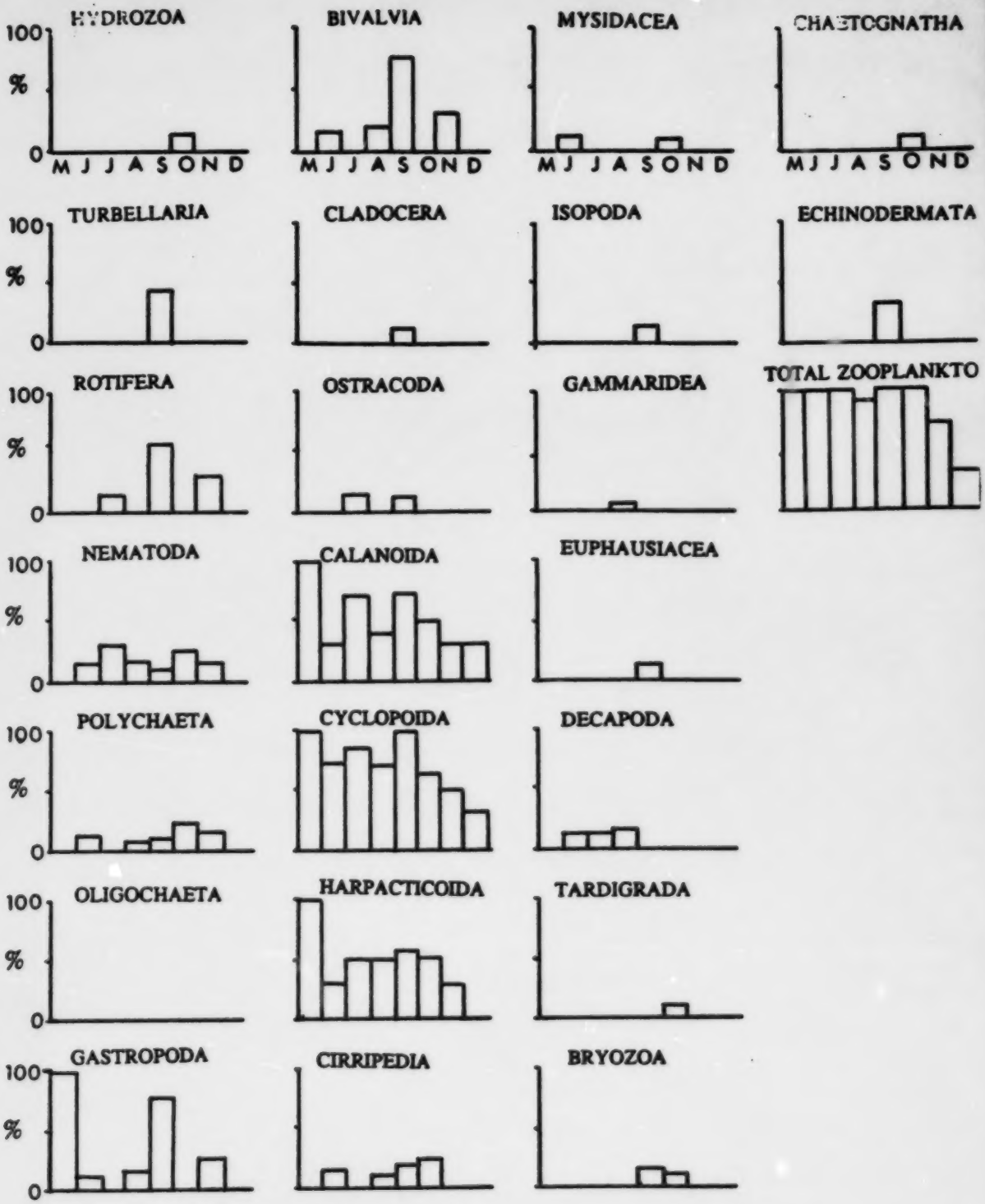

Figure 3. Seasonal variation in percent of saltwater ballast water samples containing live zooplankton.

3.7.4. Zooplankton in Montreal Harbour

Zooplankton collected in Montreal Harbour (Table 7) were, on the whole, typical of those found in other freshwater situations. The exceptions were a marine chordate (?Larvacea) and a fragment of a marine polychaete. The finding of these two organisms suggest that non-indigenous species were released in Montreal Harbour, although as yet there is no evidence that such species have been able to establish populations in the harbour. Our concern is that Montreal Harbour serves as a deballasting site for foreign vessels and simultaneously as a source of ballast water for vessels proceeding up the Seaway. Thus, if exotic species established a foothold (or even temporary populations) in the harbour, they could easily be transported into the Great Lakes.

3.7.5. Zooplankton in sediments

Our attempts to incubate ballast tank sediments and hatch diapausing eggs of zooplankton were inconclusive. We were unable to obtain sufficient quantities of sediment from any given ballast tank to be able to subject sediments to the variety of treatments required to trigger hatching in different types of organisms.

We suggest that a different type of investigation would be necessary to adequately study the possibility of transport of dormant organisms in ballast tank sediments. Probably the best way to get adequate sediments would be to sample vessels in dry dock.

There are various reasons why we suspect that dormant organisms are transported in sediments from ballast tanks. Dormant stages are resistant to a variety of environmental stresses (see Section 4) and thus may persist following salinity shocks imposed during ballast water exchange. Because dormant stages occur in the sediments, they are less likely to be swept out of ballast tanks during ballast exchange than organisms free-living in the water column. Viable eggs can survive for long periods, for example, some rotifer eggs can last for 35 years. Hallegraeffe & Bolch (1991) found that more than 70 percent of cargo vessels entering Australian ports carried sediments in their ballast tanks. Of the vessels they sampled, 40 percent carried viable dinoflagellate cysts in the sediments.

4.0. DEFINING INVASION RISK

In order to determine whether ballast water exchange eliminates species likely to pose a risk to North American inland waters, it is necessary to define the attributes of 'risky' species.

(1) Planktonic organisms are more likely to be swept up in ship's ballast water than organisms which are benthic or attached to aquatic structures. The list of organisms with planktonic stages includes numerous species of algae, zooplankton which are planktonic throughout their life histories (holoplankton) and those which are planktonic only as larval stages of benthic invertebrates (meroplankton), and larval fish (ichthyoplankton). Most planktonic organisms are small enough to pass through ballast tank intake apertures which are typically less than 2 cm in diameter (Schormann *et al.*, 1990).

(2) In order for a species to become established in the Great Lakes, it must be able to complete its full life cycle in fresh water. Relatively few marine species are found in salinities < 5 °/oo (Figure 4), but freshwater and a few brackishwater species live at 0 °/oo. Thus, freshwater and (to a lesser extent) brackishwater species are more 'risky' to the Great Lakes than are marine species.

Organisms with wide salinity tolerances (e.g. *E. affinis*) are most likely to survive the salinity changes associated with ballast water exchange. However, salinity tolerances may differ between physiological races of a species living in different areas (Green, 1968) and also may vary seasonally (Sastry, 1983).

(3) Relatively few freshwater species can survive salinities > 10 to 15 °/oo (Figure 4); however, many species of freshwater zooplankton routinely enter dormant or resting stages (usually eggs or cysts) during adverse environmental conditions such as desiccation or high or low temperatures. The ability of these resistant stages to tolerate high salinities associated with mid-ocean ballast exchange is unknown. Dispersal by means of resistant eggs or cysts is a common phenomenon, since many of these are capable of transport by wind or in animals' digestive tracts (Maguire, 1963; Proctor *et al.*, 1967). As well, many eggs and cysts may survive for years in sediments. Other life history stages capable of dispersal also display characteristics that might allow them to be effectively transported in ballast tanks even after mid-ocean exchange. For example, clams and ostracods (with tightly closed valves) sometimes attach to migrating insects which may transport them to new environments (Fryer, 1974). The suggestion by Hoestlandt (1968, cited in Mackie *et al.*, 1989) that chlorine treatments to eradicate adult zebra mussels should continue for at least seven consecutive days reflects this ability of mussels to tolerate adverse environmental conditions by closing the valves. It is possible that zebra mussels carried in ballast tanks could respond to short-term salinity increases in a similar manner.

(4) Asexual or parthenogenetic reproduction increases the effectiveness of dispersal because a single propagule may be able to establish a viable population. Many freshwater organisms have this capability. The most widespread passively-

transported inhabitants of temporary ponds are those with asexually produced cysts or eggs, and those capable of parthenogenesis (Wiggins *et al.*, 1980).

Classification of the major zooplankton taxa identified in this study based on their salinity preference, possession of a dormant stage, and ability to reproduce asexually suggests that the two categories of zooplankters most likely to be able to invade the Great Lakes are;

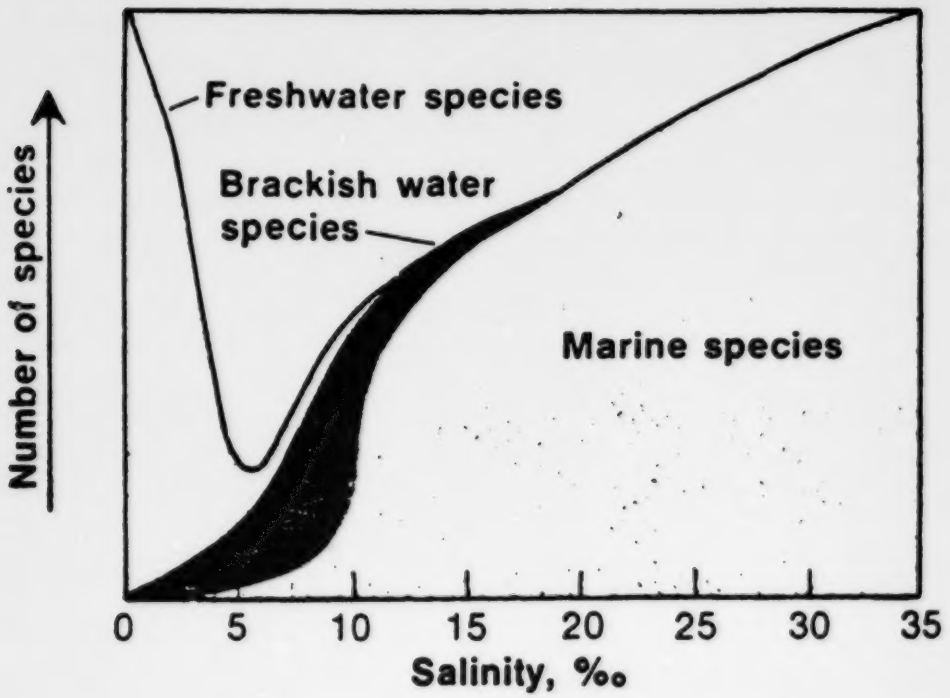

Figure 4. Effects of salinity on species numbers (from Sumich, 1980)

(1) Freshwater zooplankton with dormant stages and asexual reproduction; Turbellaria, Oligochaeta, Cladocera, Rotifera, Bryozoa, Tardigrada
(2) Freshwater zooplankton with dormant stages; Calanoida, Cyclopoida, Harpacticoida.

However, past experience reveals that these are not the only kinds of organisms capable of colonizing the Great Lakes. Organisms like the zebra mussel, with neither dormant stages nor asexual reproduction, are able colonizers. The main criteria for success of potential invaders are probably the ability to tolerate a broad range of environmental conditions, the capacity for rapid reproduction, and possession of effective dispersal mechanisms. No organism carried into the Great Lakes by ship's ballast can be considered to be completely without risk to the Great Lakes ecosystem but it is likely that levels of risk can be defined. The criteria outlined above represent a preliminary attempt to do so.

4.1. WILL THERE BE FUTURE INVASIONS?

It should be clear from our study that current ballast water control practices are achieving high compliance and effectiveness rates. It is also clear, however, that control is not perfect since some ships do not comply with the guidelines (Appendix H), live freshwater organisms still exist after mid-ocean exchange (Table 7), and foreign organisms are dumped in fresh and brackish parts of the St. Lawrence River which supply much of the ballast water released in the Great Lakes (3.2.4). The critical question is whether these loopholes in the system establish a significant invasion risk to the Great Lakes.

This is a difficult question to answer most particularly because, in addition to factors mentioned above, invasion includes a large element of chance. Even if an appropriate abundance of the relevant life stages of a species is dumped into a lake at the proper time of year, it is not certain that a population would establish. Similarly, even if very few of the wrong life stages are dumped at the wrong time of year, invasion is not impossible. The vagaries of meeting an appropriate mate, avoiding predators, and finding food are difficult to quantify into a model of invasion probability. There is current speculation that the rash of Great Lakes invasions observed during the late 20th century has occurred because the highly managed food webs of these lakes contain none of the 'resistance to invasion' (Pimm & Hyman, 1987) characteristic of natural, undisturbed communities.

As a result, it is almost impossible to say whether current levels of ballast control will eliminate future invasions. It is much more scientifically and practically defensible to conclude that invasion risk of some level will exist as long as shipsuse the St. Lawrence Seaway, and that the only sensible approach is to assiduously adhere to a carefully controlled programme of ballast regulation into the indefinite future.

5.0. SUMMARY

1. In this report we describe results of a study of ballast water carried by foreign ocean-going vessels into the Laurentian Great Lakes and upper St. Lawrence River in 1990. The purpose of the study was to use chemical (salinity) and biological (planktonic) techniques to monitor compliance of inbound vessels with the Great Lakes Ballast Water Control Guidelines (GLBWCG) and test the effectiveness of open-ocean water exchange in reducing the diversity and abundance of foreign freshwater and coastal organisms in ballast water to be released in the Great Lakes - St. Lawrence system.

2. We found that current ballast water control practices are achieving high compliance and effectiveness rates. However, control is not perfect since some ships do not comply with the guidelines, live freshwater organisms still exist after mid-ocean exchange, and foreign organisms are dumped in fresh and brackish parts of the St. Lawrence River which supply much of the ballast water released in the Great Lakes.

3. Of 455 foreign ocean-going vessels entering the St. Lawrence Seaway in 1990, 177 carried ballast water in compliance with the GLBWCG, 21 carried ballast water not in compliance with the GLBWCG, 213 carried no ballast water and no information was available for 44 vessels. Considering vessels carrying no ballast water to be in compliance, 95 percent of vessels complied with the GLBWCG. Including only vessels carrying ballast water, 89 percent were in compliance.

4. Most ballast tanks sampled (88%) contained live zooplankton, and some contained live freshwater zooplankton. Our data do not unequivocally show any ships containing live foreign freshwater zooplankton; however, 33 percent of ships originating in foreign freshwater ports and exchanging ballast water in mid-ocean carried organisms that could live in the Great Lakes. Thus effectiveness of ballast water exchange was 67 percent.

5. Eight vessels discharged non-compliance ballast water in the St. Lawrence River or Montreal Harbour, increasing the risk of establishment of foreign species. Since 40 percent of all ballast water dumped in the Great Lakes in 1990 probably came from these areas, we feel that it is imperative to enforce the 1991 guidelines that control ballast discharge above Quebec City.

6. In conformance with current Canadian Coast Guard practices, vessels considered to be in compliance with the GLBWCG included vessels which had only partially exchanged their ballast water and vessels carrying water which was not intended for discharge in the Great Lakes - St. Lawrence system. We feel that these vessels should

not be considered to be in compliance with the GLBWCG.

7. Thirty vessels (14 % of vessels with known ballast water) entering the Seaway had taken on ballast water in the Laurentian Channel, the alternate ballast exchange area for vessels unable to exchange ballast in mid-ocean. Two of these vessels had originated from freshwater European ports, and four from American ports.

8. We estimate that 236 vessels entering the Seaway carried 'unpumpable' ballast water (i.e. water remaining below the level of the ballast pump intakes). This 'unpumpable' residual water may provide a reservoir of potential invaders at the bottom of ballast tanks. These organisms would become available for discharge following re-filling of the ballast tank. Vessels containing only 'unpumpable' ballast water were not sampled in this study.

9. It is likely that dormant stages of freshwater organisms persist in sediments in the bottom of ballast tanks despite ballast water exchange. If this is the case, any ship which has ever taken on ballast in a freshwater port may pose a risk to the Great Lakes ecosystem, even if it fully complies with the ballast exchange guidelines.

6.0. RECOMMENDATIONS

(1) Discharge of ballast water not complying with the GLBWCG should be prohibited, west of 63°W longitude (i.e. freshwater or brackish portions of the St. Lawrence River system), as outlined in the 1991 GLBWCG.

(2) The Laurentian Channel or an equivalent area should be retained as an alternative saltwater ballast water exchange site for vessels unable to exchange their ballast water at sea.

(3) Ships having completed only partial ballast water exchange or report that they do not intend to discharge ballast water should not be automatically considered to be in compliance with the GLBWCG.

(4) Strategies to treat 'unpumpable' residual water should be considered. Treatment might include flushing the ballast tank with salt water in cases where the residual water originates from a freshwater area.

(5) The viability of resting eggs or dormant stages of freshwater organisms transported in sediments on the bottom of ballast tanks should be investigated.

(6) A program should be developed to monitor salinities of ballast water of ships entering the Seaway, in order to independently confirm that ballast water exchange is taking place as reported.

7.0. ACKNOWLEDGEMENTS

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Appendix A. Great Lakes Ballast Water Control Guidelines in effect in 1990.

VOLUNTARY GUIDELINES FOR THE CONTROL OF BALLAST WATER DISCHARGES FROM SHIPS PROCEEDING VIA THE ST. LAWRENCE SEAWAY TO THE GREAT LAKES

1.0 Introduction

1.1 The purpose of these voluntary Guidelines is the protection of Great Lakes waters from non-native fish and other aquatic organisms, that can be harmful to the balance of nature that now exists. When a new organism is introduced to a balanced ecosystem, negative changes may result. In the Great Lakes, there have been many aquatic organisms introduced by accident, and several of these have been very harmful. These Guidelines should reduce the probability of additional non-native species being introduced.

1.2 The best method of protecting Great Lakes waters from foreign organisms that may exist in ballast water collected in foreign harbours and nearshore areas, is for the ballast water to be exchanged in the open ocean, beyond any continental shelf or fresh water current effect. Harbour and coastal waters are often rich in living organisms that could unbalance the Great Lakes fisheries systems. Water in the open ocean contains comparatively fewer organisms. Those organisms that do exist are adapted to life in open salt water and are less likely to survive if accidentally introduced into the Great Lakes freshwater system.

1.3 The intent of these Guidelines is that all ships, destined for the St. Lawrence Seaway and Great Lakes, exchange their ballast far enough from any coastline so that there will be few organisms of any kind in the exchanged ballast water.

1.4 These voluntary Guidelines have been developed by the Canadian Coast Guard, in full consultation with the United States Coast Guard, the Great Lakes Fishery Commission, and representatives of commercial shipping. The Canadian Department of Fisheries and Oceans, and the Canadian Department of the Environment were also involved in their development, and fully support their application.

1.5 These Guidelines should not be seen as adding to or detracting from existing statutory or regulatory requirements, which will prevail in the case of conflict with the Guidelines.

Appendix A. (continued)

2.0 Short Title

2.1 These Guidelines may be cited by the short title of "Great Lakes Ballast Water Control Guidelines".

3.0 Application

3.1 The Great Lakes Ballast Water Control Guidelines apply to all vessels transiting the ECAREG VTS Zone* that are inbound for the St. Lawrence Seaway and Great Lakes.

3.2 The effective date for introduction of these Guidelines is May 1, 1989.

4.0 Implementation

4.1 Applicable ships will be requested to provide ECAREG with the following information, as part of the ECAREG interrogative:

(i) Whether ballast water is being carried;

(11) If the answer to (i) is affirmative, the minimum ocean depth and location where the ballast water was taken on or exchanged.

4.2 Vessels, subject to the Guidelines, will be requested by ECAREG to exchange any ballast water that had not been taken on in ocean depths greater than 2000 metres. The exchange should be made, at sea, as far from land as practicable, in a water depth of not less than 2000 metres.

4.3 In exceptional circumstances, where it may be impracticable to exchange ballast water as per paragraph 4.2, and for those ships that have not left the North American continental shelf on their inbound voyage, the exchange may be made in internal Canadian waters, within the Laurentian Channel and in water depths exceeding 340 metres. Such internal waters exchanges should be completed prior to the ship passing longitude 64° W and as far east as possible.

4.4 Canada's pollution prevention regulations prohibit the discharge of oil pollutant substances into any waters under Canadian jurisdiction. Where ballast water is being carried in a bunker fuel tank, or in the cargo tank of a tanker, no discharge of such ballast water is permissible within Canadian waters and any necessary discharge of such ballast water must only be to a shore reception facility.

Appendix A. (continued)

4.5 It should be noted that the stability of the ship, and any other safety considerations, remain the responsibility of the ship's master. Nothing in these Guidelines should be construed as an infringement upon that responsibility.

*Eastern Canada Vessel Traffic Services Zones. For detailed information refer to the Annual Edition of Canadian Notice to Mariners, Notice 26.

4.6 When pumping out ballast water, preparatory to an exchange in accordance with these Guidelines, the pump should be run until it loses suction, thus assuring that the tank is reasonably empty before commencing to take on the new ballast water.

4.7 A record of the salinity of the ballast water to be discharged in the Great Lakes and the location, date and time of the ballast water exchange should be entered in the ship's log book, or in other suitable documentation.

5.0 Tank Sediment Disposal

5.1 Sediment from the ballast tanks of foreign-going ships is to be disposed of only in land dumpsites.

6.0 Compliance Monitoring

6.1 If not already carried on board, ships to which these Guidelines apply will be provided with a copy by the pilot boarding the vessel at Les Escoumins. The Ballast Water Exchange Report Form (Appendix A to the Guidelines) is to be carefully completed by the ship's master. The completed Report Form will be used to verify the information previously provided to ECAREG and as a means of compliance and effectiveness monitoring of the Guidelines. The completed Report Form is to be given to the Lockmaster at the St. Lambert Lock. Samples of ballast water may also be taken for the purpose of assessing the effectiveness of the Guidelines.

6.2 These Guidelines are being introduced on a voluntary compliance basis, in the expectation of customary cooperation from the shipping industry. It is in the interests of all parties to work for their success. Evidence of non-compliance may lead to the application of regulatory controls.

6.3 It should be noted that under the Canada Shipping Act it is an offence, punishable by a fine of up to $50,000 to refuse to provide information, or to knowingly provide false information to a vessel traffic regulator, where such information is requested for the promotion of environmental protection.

Appendix B. Sources of vessel information.

(1) Marine Transit List (MTL): picked up mornings at the RIC (see below); gave position, activity (westbound, eastbound, at anchor, at dock, etc.) and destination of all vessels in the ECAREG (see below) system. At least 24 hours notice given on upbound vessels.

(2) Regional Information Centre (RIC): phone for vessel information on the DADS database (see below).

(3) ECAREG (Eastern Canadian Region): phone for vessel information on the CICS database (see below).

(4) Transport Canada Network (TCN) Computer Information System: a) DADS (Data Acquisition and Display System); most recent location and destination of vessels, transit record, b) CICS (Customer Information Control System); present and past ballast status information, previous port, destination, cargo, current draft, maximum draft.

(5) St. Lawrence Seaway Authority Inspectors: a) anticipated schedules of upbound vessels, b) ballast status of vessels inspected prior to entering the Seaway - about 20% of all vessels entering the Seaway in any given year. Notice varied from less than 1 hour to a few days.

(6) Vessel Agents: ballast or cargo status of vessels, schedules.

(7) Vessel Traffic System (VTS): direct contact with pilot and/or ship's officers while vessel is in transit between Grondines and Check-In Point 2. Up to 8 hours notice on upbound vessels.

(8) Cornwall Pilotage: times of pilotage orders for vessels approaching the seaway. Notice usually 3-12 hours.

(9) Montreal Pilotage: times of pilotage orders and movements of vessels within Montreal Harbour. Notice up to 3 hours.

(10) Saint Lawrence Seaway Authority Control: estimated time of arrival for vessels approaching St. Lambert Lock #2; direct contact with pilot and/or ship's officers while vessel is in transit between Check-In Point 2 and the American Zone of the Seaway (locks Snell and Eisenhower). Contact could be made with upbound vessels 1/2 hour before arrival at Lock #1.

(11) Eisenhower (Ike) Control: direct contact with pilot and/or ship's officers while vessel is in transit in the American Zone of the Seaway (locks Snell and Eisenhower).

(12) Boarding vessels at Montreal Harbour or St. Lambert Lock #1 (Côte St. Catherine Lock #2 for 2 downbound vessels): complete Ballast Water and Vessel Data Record Sheet (see Appendix D); take ballast water sample.

(13) Ballast Water Exchange Reports (BWER: see Appendix C): given to vessels prior to entering the Seaway; completed by ship's officers and given to the lockmaster at St. Lambert Lock #1 or Côte St. Catherine Lock #2.

Appendix C. Sample Ballast Water Exchange Report from 1990

BALLAST WATER EXCHANGE REPORT

(To be completed by the Ship's Master and given to the Lockmaster prior to ship clearing St. Lambert Lock)

NAME OF SHIP: _____

PORT OF REGISTRY: _____

OFFICIAL NO. OR CALL SIGN: _____

OWNERS: _____

AGENTS: _____

INFORMATION ON BALLAST WATER BEING CARRIED INTO THE GREAT LAKES									
LOCATION	QUANTITY (tonnes)	WHERE TAKEN ON		SALINITY (specify units)	INTENDED DISCHARGE PORT		IF EXCHANGED, WHERE WAS ORIGINAL BALLAST TAKEN ON		IN COMPLIANCE WITH GUIDELINES
		LAT	LONG		PLACE	DATE	LAT	LONG	YES OR NO
DOUBLE BOTTOMS									
FORE PEAK									
AFT PEAK									
WING TANKS									
SIDE TANKS									
DEEP TANKS									
CARGO HOLDS									

MASTER'S NAME: _____ MASTER'S SIGNATURE: _____
(Please print)

DATE: _____ LOCATION: _____

FOR COMPLETION BY ST. LAWRENCE SEAWAY INSPECTOR		
WAS BALLAST WATER SAMPLE TAKEN?	YES	NO

Appendix D. Sample vessel boarding report. GL - ____

BALLAST WATER MONITORING AND COMPLIANCE STUDY
Ballast Water and Vessel Data Record Sheet

Date: Time: Names of Field Party: _____
Boarding: St. Lambert Lock or: _____
Vessel: Name: No: Registry DWT: _____
Captain: or: Other Officers: _____
Planned Destination (Deballasting Port) in GL: _____
>If more than one port-of-call: see CCG BWER Sheet
ETA at Destination Port: _____

Ballast Water Capacity of Vessel: _____ metric tons
Ballast Water Actually Aboard Vessel: _____ metric tons
>CCG BWER Sheet shows quantity per individual tank(s)

SOURCE OF ORIGINAL BALLAST WATER (exact site:) _____
(Vessel may provide source as Lat x Long: _____
>If different tanks have water from different sources: see CCG BWER Sheet
(a) Date of Original Ballasting: _____
(b) Date of Arrival in Canada : _____ Montreal__Quebec__Other: _____
(c) [b - a =] Length of voyage in days: _____

WAS ALL BALLAST WATER EXCHANGED AT SEA?.....Yes__ No__
Where was it exchanged? (Lat x Long:) _____
Date of exchange: _____
If NO, how much WAS exchanged? _____ metric tons
Amount of original BW remaining aboard: _____ metric tons
If NO, do certain tanks (holds) have only original ballast water?
Yes:__ No:__ If YES, which one(s)? _____

HAS ANY WATER BEEN DEBALLASTED SINCE ARRIVAL IN CANADA?...Yes:__No:__
If YES, Where? _____ How Much? _____ metric tons When? _____

HAS ANY WATER BEEN BALLASTED IN CANADA?.....Yes:__No:__
If YES, Where? _____ How Much? _____ metric tons When? _____
Into which tanks was Canadian water ballasted? _____

SAMPLES

TANK	Accessed (DT,SP,NH, Other)	If DT: Rate: g/	If DT: total time	If DT: total vol	Net Mesh Size	WATER T	WATER Sal	NOTES
1.								
2.								
3.								
4.								
5.								

DT = Deck Tap; SP = Sounding Pipe; NH = Net Haul; Other: write in above

If NH: Net diameter: ____m
Height from deck to tank bottom : ____m
Height from deck to waterline : ____m
Total depth of water in tank : ____m
RATE: Enter haul time in sec : ____sec

OTHER NOTES (Photographs Taken? ____)

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Appendix E. Summary of picoplankton abundances in ballast water and Montreal harbour samples.

Table E-1. Bacterial (heterotrophic picoplankton) and autotrophic picoplankton (A.P.P.) abundances in ballast water and Montreal Harbour samples.

Vessel	Bacteria ($10^6 ml^{-1}$)	A.P.P. ($10^3 ml^{-1}$)	Vessel	Bacteria ($10^6 ml^{-1}$)	A.P.P. ($10^3 ml^{-1}$)
GL 7	0.848	0.00	GL 39	0.716	2.01
GL 8	0.470	0.00	GL 40	1.618	0.00
GL 9	0.673	0.00	GL 41	0.753	0.00
GL 10	0.587	0.00	GL 42	0.668	0.00
GL 11	0.563	0.00	GL 43	0.417	2.01
GL 12	0.761	0.00	GL 44	0.349	2.01
GL 13-1	0.876	0.00	GL 45	0.329	0.00
GL 13-2	0.738	0.00	GL 46	0.473	2.01
GL 14	0.450	0.00	GL 47	0.452	0.00
GL 15	0.708	0.00	GL 48	0.678	0.00
GL 16	0.494	0.00	GL 49	0.900	2.01
GL 17	0.607	2.68	GL 50	0.703	2.01
GL 18	0.498	0.00	GL 51	0.671	2.01
GL 19	0.342	0.00	GL 52	0.474	0.00
GL 20	0.522	4.02	GL 53	0.467	0.00
GL 21-1	1.170	0.00	GL 54	1.923	2.01
GL 21-2	0.896	2.01	GL 55	1.382	2.01
GL 22	0.532	4.02	GL 56	0.504	2.68
GL 23	0.748	3.35	GL 57	0.563	0.00
GL 24	0.749	0.00	GL 58	0.460	0.00
GL 25	0.401	0.00	GL 59	0.500	2.68
GL 26	0.422	0.00			
GL 27	0.594	0.00	Montreal	1.89	1.67
GL 28	0.420	0.00	Harbour		
GL 29	0.656	0.00			
GL 30	0.424	2.01			
GL 31	0.386	2.68			
GL 32	0.686	0.00			
GL 33	0.514	0.00			
GL 34	0.618	2.01			
GL 35	0.954	2.01			
GL 36	1.230	2.01			
GL 37	0.497	2.68			
GL 38	0.422	0.00			

Appendix E. (continued)

Table E-2. Mean, standard deviation and range of bacterial and autotrophic picoplankton abundances summarized by salinity of ballast water sample.

Salinity (°/oo)	n	Bacteria ($10^6 ml^{-1}$) Mean	S.D.	Range	Autotrophic picoplankton ($10^3 ml^{-1}$) Mean	S.D.	Range
<10	6	1.259	0.4917	0.563-1.923	1.00	1.101	0.00-2.01
20-30	5	0.729	0.1613	0.504-0.954	1.61	1.542	0.00-3.35
>30	44	0.575	0.1777	0.329-1.230	0.88	1.249	0.00-4.02

Table E-3. Mean, standard deviation and range of bacterial and autotrophic picoplankton abundances summarized by geographic origin (current ballast water).

BW Origin	n	Bacteria ($10^6 ml^{-1}$) Mean	S.D.	Range	Autotrophic picoplankton ($10^3 ml^{-1}$) Mean	S.D.	Range
Atlantic Ocean	35	0.581	0.1722	0.329-1.170	0.82	1.301	0.00-4.02
Mediterranean	4	0.631	0.2129	0.417-0.876	0.50	1.005	0.00-2.01
Laurentian Ch.	5	0.635	0.2084	0.386-0.900	1.61	1.542	0.00-3.35
Pacific Ocean	2	0.446	0.0304	0.424-0.467	1.00	1.421	0.00-2.01
Karachi	1	1.230	------	----------	2.01	-----	--------
Caribbean Sea	2	0.712	0.0580	0.671-0.753	1.00	1.421	0.00-2.01
Great Lakes, St. Lawrence R.	6	1.152	0.5851	0.473-1.923	1.34	1.038	0.00-2.01

Appendix F. Zooplankton sample collection methodolgy. (See Appendix G for typical locations of ballast tanks on ships.)

Sample Code	Tank Type	Method	Net size (Mesh/mouth diameter)	Vol. sampled (litres)	Distance net hauled x No. of hauls
GL-1-1	Aft peak	Net	110µm/30cm	566	2m x 5
GL-1-2	Aft peak	Net	53µm/13cm	120	2m x 5
GL-2-1	Double bottom	Tap	110µm	1500	
GL-2-2	Double bottom	Tap	53µm	250	
GL-3-1	Topside (P)**	Tap	41µm	3000	
GL-3-2	Topside (S)**	Tap	110µm	3000	
GL-4-1	Hold #3	Net	41µm/13cm	120	10m x 1
GL-4-2	Hold #3	Net	41µm/13cm	120	10m x 1
GL-4-3	Hold #3	Net	110µm/13cm	120	10m x 1
GL-4-4	Hold #3	Net	110µm/13cm	120	10m x 1
GL-4-6	Hold #3	Net	110µm/30cm	566	10m x 1
GL-5-1	Double bottom	Tap	41µm	2400	
GL-6-1	Fore peak	Net	41µm/13cm	120	10m x 1
GL-6-2	Fore peak	Net	41µm/13cm	120	10m x 1
GL-6-3	Fore peak	Net	110µm/30cm	566	10m x 1
GL-6-4	Fore peak	Net	110µm/30cm	566	10m x 1
GL-7-1	Wing	Net	41µm/13cm	120	2.5m x 4
GL-7-2	Wing	Net	110µm/30cm	566	2.5m x 4
GL-8-1	Double bottom	Tap	41µm	1312	
GL-9-1	Topside	Tap	41µm	2933	
GL-10-1	Double bottom	Tap	41µm	3000	
GL-11-1	Fore peak	Net	41µm/13cm	120	2.5m x 4
GL-11-2	Fore peak	Net	110µm/13cm	120	2.5m x 4
GL-12-1	Fore peak	Net	41µm/13cm	48	1m x 4
GL-12-2	Fore peak	Net	110µm/30cm	226	1m x 4
GL-13-1	Wing (P)**	Net	41µm/13cm	120	2m x 5
GL-13-2	Wing (P)**	Net	110µm/30cm	566	2m x 5
GL-13-3	Wing (S)**	Net	41µm/13cm	120	2m x 5
GL-13-4	Wing (S)**	Net	110µm/30cm	566	2m x 5
GL-14-1	Aft peak	Net	41µm/13cm	120	2m x 5
GL-14-2	Aft peak	Net	110µm/30cm	566	2m x 5
GL-15-1	Fore peak	Net	41µm/13cm	48	0.8m x 5
GL-15-2	Fore peak	Net	110µm/30cm	566	2.0m x 5
GL-16-1	Fore peak	Net	41µm/13cm	120	5m x 2
GL-16-2	Fore peak	Net	110µm/13cm	120	5m x 2
GL-17-1	Aft peak	Net	41µm/13cm	59	1m x 5

Appendix F (continued)

Sample Code	Tank Type	Method	Net size (Mesh/mouth diameter)	Vol. sampled (litres)	Distance net hauled x No. of hauls
GL-17-2	Aft peak	Net	110µm/13cm	319	1m x 5
GL-18-1	Port side	Net	41µm/13cm	107	1.5m x 6
GL-18-2	Port side	Net	110µm/13cm	107	1.5m x 6
GL-19-1	Aft peak	Net	41µm/13cm	59	1m x 5
GL-19-2	Aft peak	Net	110µm/30cm	538	1.9m x 5
GL-20-1	Deep	Net	41µm/13cm	120	2.5m x 4
GL-20-2	Deep	Net	110µm/30cm	566	2.5m x 4
GL-21-1	Double bottom	Net	110µm/13cm	107	9m x 1
GL-21-2	Double bottom	Net	41µm/13cm	59	1m x 5
GL-22-1	Wing	Tap	41µm	960	
GL-23-1	Topside	Net	41µm/13cm	120	2m x 5
GL-23-2	Topside	Net	41µm/13cm	23	2m x 1
GL-23-3	Topside	Net	110µm/30cm	566	2m x 5
GL-24-1	Deep	Net	41µm/13cm	107	3m x 3
GL-24-2	Deep	Net	110µm/13cm	107	3m x 3
GL-25-1	Wing	Net	41µm/13cm	125	1.75m x6
GL-25-2	Wing	Net	110µm/30cm	566	2.5m x 4
GL-26-1	Fore peak	Net	41µm/13cm	36	3m x 1
GL-26-2	Fore peak	Net	41µm/13cm	107	3m x 3
GL-26-3	Fore peak	Net	110µm/30cm	509	3m x 3
GL-27-1	Fore peak	Net	41µm/13cm	120	2m x 5
GL-27-2	Fore peak	Net	110µm/30cm	566	2m x 5
GL-28-1	Topside	Net	41µm/13cm	72	1m x 6
GL-28-2	Topside	Net	110µm/30cm	339	1m x 6
GL-29-1	Fore peak	Net	41µm/13cm	90	1.5m x 5
GL-29-2	Fore peak	Net	110µm/13cm	90	1.5m x 5
GL-30-1	Wing	Net	41µm/13cm	125	2m x 5
GL-30-2	Wing	Net	110µm/30cm	566	2m x 5
GL-30-3	Wing	Net	41µm/13cm	25	2m x 1
GL-31-1	Fore peak	Net	41µm/13cm	125	3.5m x 3
GL-31-2	Fore peak	Net	110µm/13cm	125	3.5m x 3
GL-32-1	Topside	Net	110µm/13cm	107	3m x 3
GL-33-1	Forward deep	Net	41µm/13cm	120	10m x 1
GL-33-2	Forward deep	Net	110µm/13cm	120	10m x 1
GL-34-1	Topside	Net	41µm/13cm	120	2m x 5
GL-34-2	Topside	Net	110µm/13cm	120	2m x 5
GL-34-3	Topside	Net	41µm/13cm	24	2m x 1

Appendix F (continued)

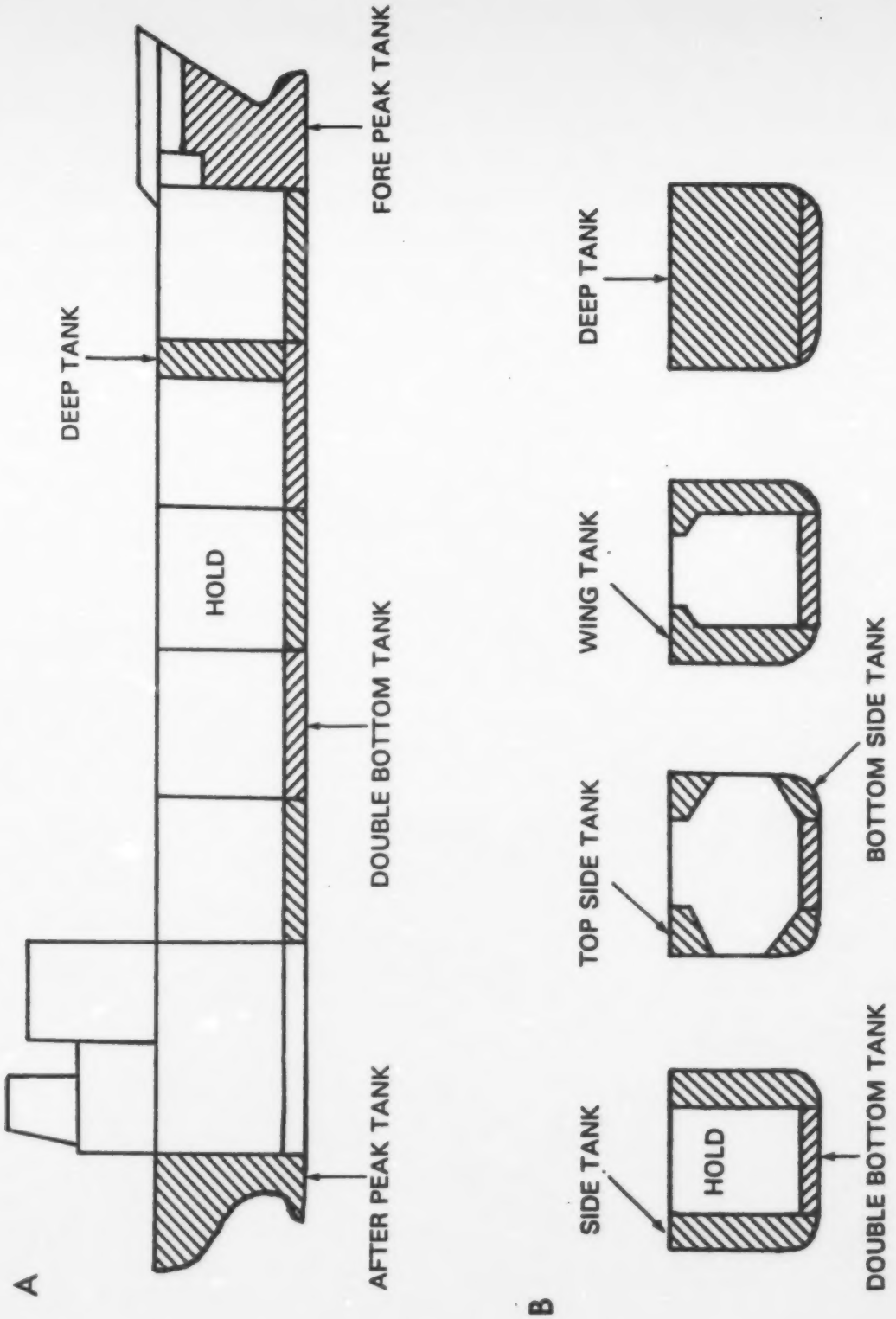
Sample Code	Tank Type	Method	Net Size (Mesh/mouth diameter)	Vol. sampled (litres)	Distance net hauled x No. of hauls
GL-35-1	Double bottom	Tap	41µm	3000	
GL-36-1	Wing	Net	110µm/13cm	120	2m x 5
GL-36-2	Wing	Net	41µm/13cm	120	2m x 5
GL-37-1	Fore peak	Net	41µm/13cm	36	3m x 1
GL-37-2	Fore peak	Net	41µm/13cm	143	3m x 4
GL-37-3	Fore peak	Net	110µm/13cm	143	3m x 4
GL-38-1	Fore peak	Net	41µm/13cm	24	2m x 1
GL-38-2	Fore peak	Net	41µm/13cm	120	2m x 5
GL-38-3	Fore peak	Net	110µm/30cm	566	2m x 5
GL-39-1	Forward deep	Tap	41µm	3000	
GL-39-2	Forward deep	Tap	110µm	1750	
GL-40-1	Hold #3	Net	41µm/13cm	107	9m x 1
GL-40-2	Hold #3	Net	110µm/13cm	107	9m x 1
GL-41-1	Aft peak	Net	41µm/13cm	72	2m x 3
GL-41-2	Aft peak	Net	110µm/13cm	72	2m x 3
GL-42-1	Topside	Net	41µm/13cm	77	1.3m x 5
GL-42-2	Topside	Net	110µm/30cm	368	1.3m x 5
GL-43-1	Hold #4	Net	41µm/13cm	120	5m x 2
GL-43-2	Hold #4	Net	110µm/30cm	566	5m x 2
GL-44-1	Fore peak	Net	41µm/13cm	107	3m x 3
GL-44-2	Fore peak	Net	110µm/30cm	509	3m x 3
GL-44-3	Fore peak	Net	41µm/13cm	36	3m x 1
GL-45-1	Fore peak	Net	41µm/13cm	59	5m x 1
GL-45-2	Fore peak	Net	110µm/13cm	59	5m x 1
GL-46-1	Aft peak	Net	41µm/13cm	59	1m x 5
GL-46-2	Aft peak	Net	110µm/30cm	283	1m x 5
GL-47-1	Topside	Net	41µm/13cm	77	1.3m x 5
GL-47-2	Topside	Net	110µm/30cm	368	1.3m x 5
GL-47-3	Topside	Net	41µm/13cm	15	1.3m x 1
GL-48-1	Fore peak	Net	41µm/13cm	120	5m x 2
GL-48-2	Fore peak	Net	110µm/30cm	566	5m x 2
GL-48-3	Fore peak	Net	41µm/13cm	59	5m x 1
GL-49-1	Fore peak	Net	41µm/13cm	107	3m x 3
GL-49-2	Fore peak	Net	110µm/13cm	107	3m x 3
GL-49-3	Fore peak	Net	41µm/13cm	36	3m x 1
GL-50-1	Topside	Net	41µm/13cm	59	1m x 5
GL-50-2	Topside	Net	110µm/30cm	283	1m x 5

Appendix F (continued)

Sample	Tank Type	Method	Net size (Mesh/mouth diameter)	Vol. sampled (litres)	Distance net hauled x No. of hauls
GL-50-3	Topside	Net	41µm/13cm	12	1m x 1
GL-51-1	Fore peak	Net	41µm/13cm	143	6m x 2
GL-51-2	Fore peak	Net	110µm/13cm	143	6m x 2
GL-52-1	Fore peak	Net	41µm/13cm	120	2m x 5
GL-52-2	Fore peak	Net	110µm/30cm	566	2m x 5
GL-52-3	Fore peak	Net	41µm/13cm	24	2m x 1
GL-53-1	Double bottom	Net	41µm/13cm	143	6m x 2
GL-53-2	Double bottom	Net	110µm/30cm	678	6m x 2
GL-53-3	Double bottom	Net	41µm/13cm	72	6m x 1
GL-54-1	Aft peak	Net	41µm/13cm	120	2m x 5
GL-54-2	Aft peak	Net	110µm/30cm	566	2m x 5
GL-55-1	Topside	Net	41µm/13cm	72	1m x 6
GL-55-2	Topside	Net	110µm/30cm	339	1m x 6
GL-55-3	Topside	Net	41µm/13cm	12	1m x 1
GL-56-1	Fore peak	Net	41µm/13cm	107	3m x 3
GL-56-2	Fore peak	Net	110µm/30cm	509	3m x 3
GL-56-3	Fore peak	Net	41µm/13cm	36	1m x 3
GL-57-1	Wing	Net	41µm/13cm	143	12m x 1
GL-57-2	Wing	Net	110µm/13cm	143	12m x 1
GL-58-1	Wing	Net	41µm/13cm	72	1m x 6
GL-58-2	Wing	Net	110µm/30cm	339	1m x 6
GL-58-3	Wing	Net	41µm/13cm	12	1m x 1
GL-59-1	Topside	Net	41µm/13cm	90	1.5m x 5
GL-59-2	Topside	Net	110µm/13cm	90	1.5m x 5
MH-1-1	Section 67	Net	41µm/13cm	120	10m x 1
MH-1-2	Section 67	Net	110µm/30cm	566	10m x 1
MH-2-1	Section 54	Net	41µm/13cm	120	10m x 1
MH-2-2	Section 54	Net	110µm/30cm	566	10m x 1
MH-3-1	Section 45	Net	41µm/13cm	120	10m x 1
MH-3-2	Section 45	Net	110µm/30cm	566	10m x 1
MH-4-1	Section 40	Net	41µm/13cm	120	10m x 1
MH-4-2	Section 40	Net	110µm/30cm	566	10m x 1

* net hauls corrected for net efficiency of 90% (13 cm nets) and 80% (30 cm nets)
** port (P) and starboard (S) are indicated where more than one tank per ship were sampled

Appendix G. Typical locations of ballast tanks sampled in this study



Appendix H. List of upbound foreign ocean-going vessels carrying ballast water.

Sampled vessels are indicated with asterisk. The date the vessel entered the Seaway, listed here, may differ from the date of sampling if the vessel was sampled in Montreal Harbour. The source of the ballast water carried upon entering the St. Lawrence Seaway (Current BW) and the source of the previous ballast water carried (Previous BW) is recorded where known. Whether the vessels fully exchanged (Y), partially exchanged (P), discharged (D), took on (T) or flushed (F) the ballast water is recorded (Ex), as well as whether (Y) or not (N) the procedure was in compliance with the ballast water exchange guidelines (Co), and whether (Y) or not (N) the ballast water carried was considered high risk (Ri). Non-compliance ballast water originating from the St. Lawrence drainage was considered less risky than that from other waters.

Vessel Name	Date M	D	Current BW	Previous BW	Ex	Co	Ri
Nordic	3	28	NBWOB	Montreal	T	Y	N
Federal Inger	4	2	Atlantic	Laurentian Ch	Y	Y	N
Hercegovina	4	8	Unknown	Atlantic	Y	Y	N
Animar	4	9	Thessalonika Gr	Atlantic	Y	Y	N
Leo M	4	9	Unknown	Atlantic	Y	Y	N
Gerdt Oldendorff	4	11	EngCh <100m	Atlantic	F	N	Y
Mary W	4	11	NBWOB	St. Lawrence R.	T	Y	N
Ziemia Tarnowska	4	12	Leixoes Port.	Atlantic	Y	Y	N
Proof Trader	4	13	Atlantic		Y	Y	N
Punica	4	14	Unknown	Atlantic	Y	Y	N
Jag Vijay	4	15	Newark USA	Laurentian Ch.	Y	Y	N
Fonnes	4	16	NBWOB	Sorel	T	Y	N
Ziemia Suwalska	4	17	Unknown	Atlantic	Y	Y	N
Kallio	4	18	Kalamata Gr	Atl.-Laur. Ch.	Y	Y	N
Mountain Blossom	4	18	Unknown	Atlantic	Y	Y	N
Apj Anjli	4	19	Ceyhan Tu		N	N	Y
La Richardais	4	19	Rotterdam	Rott. Atlantic	P	N	Y
Olympic Miracle	4	22	Unknown	Atlantic	Y	Y	N
Ais mamas	4	22				Y	N
Olympus	4	24	Unknown	Laurentian Ch.	Y	Y	N
Ivan Susanin	4	26	Murmansk USSR	Atlantic	Y	Y	N
State of Orissa	4	28	Unknown	Laurentian Ch.	Y	Y	N
Lora C	4	30	Unknown	Laurentian Ch.	Y	N	N
Lt Argosy	5	3	NBWOB	Atlantic	T	Y	N
Scan Trader	5	3	NBWOB	St. John NB	T	N	Y
Pontokratis	5	5	NBWOB	Atlantic	T	Y	N
Astart	5	6	Unknown	Atlantic	Y	Y	N
Lake Challenger	5	7	Pacific	Atlantic	Y	Y	N
Island Gem	5	8	Antwerp Be	Atlantic	Y	Y	N
Seaking	5	13	Unknown	Atlantic	Y	Y	N
Olympic Dignity	5	15	Immingham UK	Atlantic	Y	Y	N

Appendix H. (continued)

Vessel Name	Date M	D	Current BW	Previous BW	Ex	Co	Ri
Sunny Blossom	5	15	NBWOB	Atlantic	T	Y	N
Indira Mahal	5	16	NBWOB	Atlantic	T	Y	N
Nomadic Pollux	5	17	NBWOB	St.Lawr.R. Ports	T	Y	N
Thorscape	5	19	Montreal Durban	Prev.+Cabot Str.	P	N	Y
Fairlane	5	21	Atlantic		T	Y	N
Titan Scan	5	21	Kamazawa Ja	Pac. St.Lawr.R.	Y T	Y	N
Ziemia Lubelska	5	21	Morocco	Atlantic	Y	Y	N
Andrew H	5	22	Unknown	Atlantic	Y	Y	N
Federal St. Laurent	5	24	Unknown	Atlantic	Y	Y	N
Shimone	5	24	Unknown	Atlantic	Y	Y	N
Fairnes	5	25	Atlantic			Y	N
Pontoporos	5	25	Unknown	Atlantic	Y	Y	N
Suntempest	5	25	Unknown	Montreal	F	Y	N
Leo M	5	26	Unknown	Atlantic	Y	Y	N
Istrian Express	5	28	Unknown	Atlantic	Y	Y	N
Monte Bonita	5	29	Atlantic			Y	N
Yin Kim	5	29	Unknown	Atlantic	Y	Y	N
Animar	5	30				Y	N
Dooyang Frontier	6	2			Y	Y	N
Loretta V	6	2	Unknown	Atlantic	Y	Y	N
Petka	6	2	NBWOB	Atlantic	T	Y	N
Lok Prem	6	4	Unknown	Atl.+Laur. Ch.	Y	Y	N
Anangel Prosperity *	6	6	LeHavre Fr	Atlantic	Y	Y	N
Kallio	6	6	Unknown	Atlantic	Y	Y	N
Gur Master	6	6	Philadephia USA	Atlantic	Y	Y	N
Gefion	6	8	Unknown	Atlantic	Y	Y	N
Sounion	6	9	Atlantic			Y	N
Gogo Chemstar	6	9	NBWOB	Quebec	T	Y	N
Lara S	6	10	Unknown	Atlantic	Y	Y	N
Ziemia Chelminska *	6	13	Montoir Fr	Atl.+Montreal	P T	N	Y
Al Samad *	6	14	Bejaia Al	Cabot St.+L.Ch.	Y	Y	N
Chippewa	6	16				Y	N
Astral Ocean	6	17				Y	N
Lux Challenger	6	17	UK Coast	Atlantic	Y	Y	N
Lake Anina	6	17	Unknown	Atlantic	Y	Y	N
Anangel Horizon *	6	18	Mediterranean	Atlantic	Y	Y	N
Pluto	6	20	New Haven USA	Cabot St.-L. Ch.	Y	Y	N
Malinska *	6	21	Antwerp Be	Atlantic	Y	Y	N
Thor 1	6	21	NBWOB	L.Ch.+Montreal	T	Y	N
Norman Sirina *	6	22	NBWOB	Montreal	T	Y	N
Solta	6	23	NBWOB	Laurentian Ch.	T	Y	N

Appendix H. (continued)

Vessel Name	Date M	Date D	Current BW	Previous BW	Ex	Co	Ri
Federal Thames	6	24	Holland+France	Cabot St.-L. Ch.	Y	N	N
Hoko Nova	6	25	NBWOB	Caribbean	T	Y	N
Firat	6	30	Atlantic			Y	N
Elikon	7	1	NBWOB	Atlantic	T	Y	N
Beeco American	7	1	Asian+USA Ports		N	Y	N
Leo M	7	2				Y	N
Sun Ocean *	7	3	Caribbean+USA	Carib.Atl.L.Ch.	N Y T	Y	N
Finnfighter	7	4	Unknown	Atlantic	Y	Y	N
Polar Queen	7	5				Y	N
Ivi	7	6	NBWOB	Atlantic	T	N	Y
Dugi Otok	7	6	NBWOB	Montreal	T	Y	N
Aquarius	7	6	Farsund No		N	Y	N
Astart	7	7	Unknown	Atlantic	Y	Y	N
Freenes	7	8	Newcastle UK	Laurentian Ch.	Y	Y	N
Sunbrisa	7	9	Unknown	Atl.-Laur.Ch.	Y	N	Y
Plitvice	7	11	Unknown	Atl. Quebec	Y T	Y	N
Aleksandr Starostenko *	7	12	North Sea	Atlantic	Y	Y	N
Olympic Promise	7	13	Savannah USA	Atlantic	Y	Y	N
Pokinnen	7	14	Unknown	Atlantic	Y	Y	N
Kallio	7	15				Y	N
Orient Sun	7	15	NBWOB	Baie Comeau	T	Y	N
Akmi	7	15	NBWOB	Montreal	T	Y	N
Adele R	7	15				Y	N
La Frenais	7	17	Atlantic		T	Y	N
Heruvim	7	17	NBWOB	Montreal	T	Y	N
Sun Stinnes	7	18	San Juan Pto.Rico			Y	N
Asian Erie	7	21	Japan	Cabot St.-L.Ch.	Y	Y	N
Argus	7	22	Unknown	Laurentian Ch.	Y	Y	N
Norchem	7	22	Unknown	Laurentian Ch.	Y	Y	N
Ziemia Gnieznienska	7	22				Y	N
Nordholm	7	23				Y	N
Thorscape	7	26	Montreal	Montreal	N T	Y	N
Kavo Yerakas *	7	27	North Sea	Atlantic	Y	Y	N
Caribbean Princess	8	1	NBWOB	St. John NB	T	Y	N
Furunes *	8	2	Baltic Sea	Atlantic	Y	Y	N
Consensus Sun	8	2	Pacific		T	Y	N
Arktis Pearl	8	3	Atlantic	Laurentian Ch.	Y	Y	N
Johanna K	8	4	Unknown	Atlantic	Y	Y	N
Zaglebie Medziowe	8	4	Atlantic			Y	N
Leo M *	8	7	Pasajes Sp	Atlantic	Y	Y	N
Federal Polaris	8	7	Unknown	Laurentian Ch.	Y	Y	N

Appendix H. (continued)

Vessel Name	Date M	D	Current BW	Previous BW	Ex	Co	Ri
Norchem	8	8	Unknown	Laurentian Ch.	Y	Y	N
Selkirk Settler	8	13			Y	Y	N
Stolt Castle *	8	14	Rotterdam+Med.	Prev.+Atlantic	P	N	Y
Pamisos	8	14	Unknown	Atlantic	Y	Y	N
Malinska	8	17	NBWOB	Contrecoeur	T	Y	N
Anatoliy Lyapidevskiy *	8	21	Skagerrak+N.Sea	Atlantic	Y	Y	N
Korean Trader *	8	22	Camden USA	Atlantic	Y	Y	N
Aleksandr Starostenko *	8	23	North Sea+Atl.	Atlantic	Y	Y	N
Consensus Sea *	8	23	Caribbean Sea	Atlantic	Y	Y	N
Thor 1 *	8	24	Montreal	Atl+Montreal	Y T	Y	N
Caribbean Queen	8	25	NBWOB	Atlantic	T	Y	N
Chippewa	8	26	Atlantic	St. Lawrence R.	Y	Y	N
Kallio *	8	27	Pasajes Sp	Atlantic	F	N	Y
Stolt Sydness	8	29	NBWOB	Atlantic	T	Y	N
Project Arabia	8	30	Unknown	Atlantic	Y N	Y	N
Federal Saguenay *	8	31	Huelva Sp	Atlantic	Y	Y	N
Omisalj	9	3	Teesport UK	Atl.L.Ch.St.L.R.	Y T	Y	N
Seaking	9	8	NBWOB	Montreal	T	Y	N
Saint Laurent *	9	12	Tokyo Bay Ja	Pacific	Y	Y	N
Mehmet Emin	9	13	Il'Ichevsk USSR	Atlantic	P	N	Y
Federal Inger	9	13	NBWOB	Montreal	T	Y	N
Leo M	9	16	Unknown	Atlantic	Y	Y	N
Socrates *	9	17	Long Is.Sd. USA	Laurentian Ch.	Y	Y	N
Miss Aliki *	9	18	Newark USA	Atlantic	P F	N	Y
Berta Dan *	9	23	NBWOB	St. Lawrence R.	T	Y	N
Gretke Oldendorff	9	23	Japan	Atl. Montreal	Y T	Y	N
Rubi	9	23	NBWOB	Montreal	T	Y	N
Mizoram	9	23	Unknown	Bay Of Bengal	Y	Y	N
Mountain Blossom	9	23	Unknown	Atlantic	Y	Y	N
Alexandria *	9	23	Rotterdam Ho	Atlantic	Y	Y	N
Kupa	9	25	Hudson R. USA		N	N	Y
Conti Blue	9	27	Adriatic Sea	Laurentian Ch.	Y D	Y	N
Kallio *	10	2	Pasajes Sp	Atlantic	Y	Y	N
Thorscape	10	3	St. Lawrence R.	Atl. Montreal	Y T	Y	N
Sagittarius	10	7	Atlantic			Y	N
Lake Challenger	10	8	Unknown	Pacific	Y	Y	N
Aleksandr Starostenko	10	10	Unknown	Atlantic	Y	Y	N
Kavo Yerakas *	10	12	NBWOB	Montreal	T	Y	N
Sibanimar *	10	12	NBWOB	Str. of Florida	T	Y	N
Skaw Trader *	10	14	NBWOB	Atlantic + Med.	T	Y	N
Kupari	10	17	Mediterranean	Atlantic	Y	Y	N

Appendix H. (continued)

Vessel Name	Date M	D	Current BW	Previous BW	Ex	Co	Ri
Freenes	10	17	Unknown	Laurentian Ch.	Y	Y	N
Pontoporos *	10	18	Tobruk Li	Atl.Med.Montreal	Y T	Y	N
Ikan Sepat	10	20	Antwerp Be	Atlantic	Y	Y	N
Bosporus	10	20	Cienfuegos Cu	Atlantic	Y	Y	N
Thor 1 *	10	22	Can. Ports Atl.	Montreal	Y T	Y	N
Pamisos *	10	23	NBWOB	Atlantic	T	Y	N
Federal Saguenay *	10	24	North Sea	St. Lawrence R.	D T	N	N
Fullnes	10	25	Atlantic			Y	N
Ziemia Gnieznienska	10	27			Y	Y	N
Stolt Castle	10	27	NBWOB	Atlantic	T	Y	N
Nordic	10	29	Atlantic			Y	N
Selkirk Settler *	10	30	Ghent Be Atl.	Laurentian Ch.	Y	Y	N
Nordstrand	10	30	Fortaleza Br	Atlantic	Y	Y	N
Leo M *	10	31	Pasajes Sp	Atlantic	Y	Y	N
Green Laker *	11	1	PhiladelphiaUSA	Atl.-Laur.Ch.	Y D	Y	N
General Cabal	11	4	NBWOB	CharlottetownPEI	T	N	Y
Helena Oldendorff	11	5	NBWOB	Atlantic	T	Y	N
Sir John *	11	6	Manfredonia It	Atlantic	Y	Y	N
Fulvia *	11	14	Mexico L.Panama	Jamaican Ch.	Y	Y	N
Consensus Star	11	15	NBWOB	Atlantic	T	Y	N
State of Manipur	11	15	Unknown	Laurentian Ch.	Y	Y	N
Project Orient	11	17	NBWOB	Atlantic	T	Y	N
Budowlany	11	19	Unknown	Atlantic	Y	Y	N
Staberg	11	19	NBWOB	Montreal	T	Y	N
Kallio *	11	20	Pasajes Sp	Atlantic	Y	Y	N
Federal Agno	11	20	Unknown	Laurentian Ch.	Y T	Y	N
Kamtin	11	20	Falmouth UK	Atlantic	Y	Y	N
Bahia De Manzanillo	11	21	Unknown	Bay of Campeche	Y	Y	N
Ziemia Tarnowska	11	21	Unknown	Atl. Contrecoeur	Y T	Y	N
Project Carrier *	11	21	Sea Of Japan	Pac. Acapulco	P T	N	Y
Baronia	11	22	Antwerp Be	Atlantic	Y	Y	N
Olympic Miracle	11	22	Unknown	St. Lawrence R.	Y	N	N
Stolt Aspiration	11	23	NBWOB	Quebec	T	Y	N
Darya Kamal	11	24	Rotterdam Ho	Atlantic	Y	Y	N
Apj Anand	11	25	Unknown	Laurentian Ch.	Y	Y	N
Adele R	11	25	Atlantic			Y	N
Chippewa	11	26	NBWOB	Quebec	T	Y	N
Federal Fuji	12	1	NBWOB	Pacific	T	Y	N
Walvis Bay	12	1	HudsonR.USA	Sorel	N T	N	Y
Nordic *	12	4	Rotterdam Ho	Trois-R. Montreal	Y	N	N
Bahia De Cardenas	12	4	Lake Ontario	L. Ont. Str. Fla.	N T	Y	N

Appendix H. (continued)

Vessel Name	Date M	D	Current BW	Previous BW	Ex	Co	Ri
Thorscape *	12	4	Montreal L.Ont.	Atlantic	P	Y	N
Leo M *	12	6	Pasajes	Atlantic	Y	Y	N
Proof Trader *	12	6	Toronto Laur.Ch.	Atlantic	Y	Y	N

Appendix I. List of upbound foreign ocean-going vessels carrying no ballast water on board. Where known, the previous ballast water is recorded.

Vessel Name	Date M	Date D	Previous Ballast Water	Vessel Name	Date M	Date D	Previous Ballast Water
Olympic Melody	4	9		Diamente	6	18	
Thor 1	4	13		Fullnes	6	19	
Bergen Bay	4	15		Rixta Oldendorff	6	19	
Anemos	4	17		Selkirk Settler	6	19	
Fullnes	4	18		Eurojoy	6	20	
Golconda L	4	18		Ziemia Zamojska	6	20	
Furunes	4	19		Federal Calumet	6	22	
Federal Ottawa	4	20		Canada Marquis	6	25	
Seahorse	4	20		Ingrid Leonhardt	6	26	
La Frenais	4	21		Saskatchewan Pioneer	6	27	Atlantic
Finnarctis	4	22		Stolt Castle	6	27	
Atlanta	4	23		Federal Danube	6	27	
Lake Shidaka	4	23		Bremon	6	29	
Ziemia Zamojska	4	24		Lucky Man	6	30	
Regina Oldendorff	4	28		Punica	7	2	
Elikon	4	29		Anna	7	3	
Stolt Accord	4	30		Mar Caterina	7	6	
Mar Caterina	5	5		Baltic Trader	7	10	
Hydra	5	8		Mountain Blossom	7	11	
Olympic Merit	5	8		Zafiro	7	12	
Maria G L	5	12		Caroline Oldendorff	7	14	
Svangen	5	15		Arktis Ocean	7	14	Victoria R.
Stolt Sakra	5	16					Australia
Ira	5	17		Caribbean Queen	7	14	
Trovatore	5	17		Stolt Sydness	7	15	
Apj Anand	5	20		Fastnes	7	15	
Soren Toubro	5	20		Kartal 7	7	16	Laurentian
Liberty Sky	5	22					Channel
Alsyta Smits	5	25		Omisalj	7	19	
Ravenna	5	26	Setubal Po +	Romo Maersk	7	19	
			Atlantic	Federal Bergen	7	20	
Federal Inger	5	27		Federal St. Clair	7	21	
Proof Trader	5	31		Ikan Selayang	7	22	
Mountain Blossom	5	31		Stolt Crown	7	25	
Green Laker	5	31		Federal Schelde	7	25	
Lefkothea L	6	6		Shoun Nectar	7	26	
Selnes	6	6		Lake Anina	7	26	
Malaysian Pride	6	8		Paolo Pittaluga	7	28	
Mar Caterina	6	8		Federal Agno	7	29	
Stolt Crown	6	11		Huron	7	31	
Bahia De Cardenas	6	11		Olympic Merit	7	31	

Appendix I. (continued)

Vessel Name	Date M	Date D	Previous Ballast Water
Mar Caterina	8	3	
Selnes	8	3	
Pomorze Zachodnie	8	4	
Dadi	8	4	
Scandinavian Express	8	6	
La Richardais	8	7	
Christina W	8	12	
Regina Oldendorff	8	13	
Stefanos	8	14	
Anna	8	15	
Federal Maas	8	16	
Darya Chand	8	16	
Federal Ottawa	8	17	
Alberta	8	25	
Rio Vista	8	26	
Soren Toubro	8	27	
Rio Colorado	8	27	
Olympic Miracle	8	29	
Ziemia Zamojska	8	31	
Capetan Michalis	9	1	
Mar Caterina	9	1	
Mary Anne	9	6	Laurentian Channel
Rio Orinoco	9	8	
Budowlany	9	8	
Olympic Merit	9	10	
Federal Rhine	9	11	
Deneb	9	11	
General Vargas	9	12	
Canada Marquis	9	13	
Bergen Sea	9	13	
Apj Anjli	9	14	
Lt Argosy	9	15	
Stolt Castle	9	15	
Liberty Sky	9	15	
Bahia De Cardenas	9	19	
Consensus Star	9	19	Atlantic
Crystal B	9	21	Atlantic
Olympic Mentor	9	22	
Lora C	9	24	
Federal St. Clair	9	25	
Ziemia Suwalska	9	28	
Federal Calumet	9	29	
Super Spirit	9	29	
Federal Nord	9	30	
Selnes	9	30	
Lori J	9	30	
Mar Caterina	10	4	
Starman Asia	10	5	
Pomorze Zachodnie	10	5	
Chippewa	10	5	Atlantic
Federal Danube	10	5	
Lex Almendro	10	6	
Norchem	10	6	
Regina Oldendorff	10	9	
Federal Schelde	10	12	
Anna	10	12	
Federal Ottawa	10	13	
Federal Fuji	10	13	
Docegulf	10	14	
Stolt Sydness	10	14	
Atlanta	10	17	
Sava	10	17	
Castano	10	18	
Rio Colorado	10	19	
Federal Thames	10	20	Atlantic
Broompark	10	20	Atlantic
Federal Hudson	10	20	
Fastnes	10	21	
Cvijeta Zuzoric	10	24	
Federal Maas	10	26	
Korean Trader	10	27	
Bijelo Polje	10	27	
Proof Trader	10	30	
Alberta	10	31	
Evimeria	10	31	
La Richardais	11	2	
Peonia	11	2	
Stolt Titan	11	2	
Petka	11	3	
Bergen Bay	11	4	
Ziemia Zamojska	11	5	
Ikan Selayang	11	7	Atlantic
Friendly Islands	11	9	

Appendix I. (continued)

Vessel Name	Date M	Date D	Previous Ballast Water	Vessel Name	Date M	Date D	Previous Ballast Water
Grigorpan	11	10		Vulcan	11	23	Atlantic
Deneb	11	10		Loretta V	11	23	
Omisalj	11	11		Apj Anjli	11	23	
La Frenais	11	12		Anangel Triumph	11	24	
Puhos	11	14		Astart	11	24	Atlantic
Stolt Accord	11	14		Honesty	11	24	Laurentian Channel
Olympic Phoenix	11	15					
Bronson	11	16		Federal Ottawa	11	24	
Yin Kim	11	16	Pacific	Lake Shidaka	11	24	
Diamente	11	18		Federal Danube	11	26	
Liberty Sky	11	18		Falknes	11	28	
Gemini	11	19	Atlantic	Crystal B	11	28	
Nordmark	11	19		Silver Leader	11	28	
Eurostar	11	19		Federal Bergen	11	28	
Canada Marquis	11	19		Mary Anne	11	28	
Federal Rhine	11	20		Ziemia Suwalska	11	28	
Ira	11	20		Mountain Blossom	11	29	
Anangel Fidelity	11	20		Stolt Castle	11	29	
General Vargas	11	20		Federal Calumet	12	1	
Lori J	11	21		Itabo	12	2	
Ais Mamas	11	21		Apt Mariner	12	2	
Akmi	11	22		Federal Schelde	12	4	
Suntempest	11	22		Thanassakis S	12	5	
Diamond	11	22		Kapitan Vodyenko	12	6	
Saskatchewan Pioneer	11	22		Albonica	12	8	
Mar Caterina	11	22		Caribbean Queen	12	10	

Appendix J. Foreign ocean-going vessels for which no ballast water information was available. The previous port or country is listed where known.

Vessel Name	Date M	Date D	Previous Port/ Country	Vessel Name	Date M	Date D	Previous Port/ Country
Federal Nord	3	30		La Frenais	5	8	
Federal Saguenay	4	3		Nordic	5	10	
Broompark	4	7		Bihac	5	12	
Federal Calumet	4	9		Berta Dan	5	12	
Falknes	4	10		Bronson	5	13	
Chippewa	4	12		Omisalj	5	15	
Federal Maas	4	13		Federal Schelde	5	16	
Stolt Sydness	4	17		Ziemia Gnieznienska	5	16	
Arosa	4	19		Federal St. Clair	5	18	
Akranes	4	21		Adele R	5	23	
Federal Danube	4	22		Stolt Sydness	6	2	
Stolt Aspiration	4	24		Federal Maas	6	6	
Federal Thames	4	25		Mary W	6	8	
Malinska	4	25		Federal Ottawa	6	23	
Rio Colorado	4	26		Caribbean Prince	6	28	
Darya Ma	4	27		Deneb	6	30	St. John NB
Miss Aliki	4	28		Sac Malaga	7	21	
Sibanimar	4	28		Federal Thames	8	12	
Sava	4	29		Adele R	9	8	
Anna	5	4		Stolt Aspiration	10	2	Quebec City
Lady Franklin	5	4		Federal Polaris	10	29	
Lt Odyssey	5	8		Tatiana L	11	18	Antwerp Belgium

Appendix K. Quantitative zooplankton counts for samples from vessels with salinity < 30 °/oo, those which had not exchanged ballast water, and those which had originated from a freshwater port and exchanged ballast in salt water. The number of days elapsed since the previous major introduction of water to the tank sampled is recorded after the first sample code for each ship. Assessment of zooplankton condition is based on preliminary analysis of unpreserved samples, and taxonomic identification was carried out using preserved specimens.

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-3-1 (10)	Nematoda	n	1
	Keratella sp.	n	2560
	Kellicottia longispina	n	7
	Daphnia longispina	n	16
	Bosmina longirostris	n	15
	Chydorus brevilabris	n	3
	Pseudochydorus globusus	n	<1
	nauplius	y	16
	Cyclops sp.	n	4192
	Microsetella norvegica	y	3680
	Chironomidae larva	n	<1
GL-3-2	Kellicottia longispina	n	4
	Etione sp. metatrochophore II	n	<1
	Acarina (Forelia sp.)	n	<1
	Daphnia longispina	n	3
	Bosmina longirostris	n	17
	Chydorus brevilabris	n	3
	nauplius	n	1
	Cyclops sp.	n	939
	Microsetella norvegica	y	1952
	Cirripedia cypris	n	<1
	Gammarus sp. immature	n	<1
	Chironomidae larva	n	<1
GL-6-1 (1)	Cnidaria	n	8
	Keratella sp.	y	40667
	Kellicottia longispina	y	3333
	Polyarthra remata	y	533
	Brachionus sp.	?	1267
	Lecane sp.	?	1933
	Asplanchna sp.	y	67
	Nematoda	?	8
	Daphnia galeata mendotae	?	8
	Bosmina longirostris	y	26267
	Chydorus brevilabris	?	8
	nauplius	y	158
	copepodites	y	175
	Eurytemora affinis	y	8
	Diaptomus sp.	y	8

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Diaptomus sp.	y	8
	Limnocalanus macrurus	y	8
	Diacyclops thomasi	y	75
	Bryocampus sp.	y	8
	Ostracoda	y	8
	Chironomidae larva	?	8
GL-6-2	Asplanchna sp.	?	8
	Lecane sp.	?	267
	Keratella sp.	?	46667
	Kellicottia longispina	?	458
	Polyarthra sp.	?	2133
	Synchaeta sp.	?	67
	Brachionus sp.	?	67
	Nematoda	?	42
	Acarina (Pionidae nymph)	?	8
	Acarina (Monostigmata)	?	8
	Ceriodaphnia sp.	?	17
	Bosmina longirostris	?	18667
	Chydorus brevilabris	?	33
	nauplius	?	325
	Eurytemora affinis	?	142
	Diacyclops thomasi	?	133
	Bryocampus sp.	?	8
GL-6-3	Keratella sp.	?	2
	Kellicottia longispina	?	5
	Polyarthra sp.	?	2
	Euchlanis sp.	?	4
	Nais simplex	?	2
	Daphnia galeata mendotae	?	4
	Dahnia retrocurva	?	2
	Bosmina longirostris	?	3187
	Chydorus brevilabris	?	25
	nauplius	?	4
	copepodites	?	71
	Epischura lacustris	?	2
	Eurytemora affinis	?	41
	Leptodiaptomus minutus	?	12
	Leptodiaptomus ashlandi	?	2
	Diacyclops thomasi	?	101
	Mesocyclops edax	?	2

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-6-4	Kellicottia longispina	?	42
	Brachionus sp.	?	28
	Euchlanis sp.	?	19
	Daphnia galeata mendotae	?	4
	Ceriodaphnia sp.	?	4
	Bosmina longirostris	?	8760
	Bosmina coregoni	?	1643
	Chydorus brevilabris	?	2
	nauplius	?	94
	Limnocalanus macrurus	?	4
	Epischura lacustris	?	2
	Eurytemora affinis	?	28
	Skistodiaptomus oregonensis	?	2
	Diacyclops thomasi	?	156
	unidentified	?	2
GL-7-1 (6)	Bivalvia veliger	y	8
	Bosmina longirostris	n	8
	nauplius	y	283
	Eurytemora affinis	y	292
	Cyclopoida (unidentified)	n	25
	Microsetella norvegica	?	8
	Mysidacea	y	25
GL-7-2	Hydrozoa colony	?	2
	Gastropoda veliger	n	2
	Kellicottia longispina	n	5
	Bosmina sp.	n	9
	nauplius	y	820
	Eurytemora affinis	y	288
	Oithona sp.	?	95
	Harpacticoida (unidentified)	?	2
	Mysidacea	y	7
	Decapoda (Caridea)	y	4
	Hyperiidea embryo	n	25
GL-13-1 (17)	Nematoda	y	25
	Gastropoda veliger	n	8
	Keratella sp.	n	8
GL-13-2	Keratella sp.	n	2
	Bosmina sp.	n	2
	Cyclopoida (unidentified)	n	2

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-13-3	Nematoda	y	8
	Bosmina longirostris	n	8
	nauplius	n	17
GL-13-4	Polychaeta	y	2
	Rotifera	n	2
	Bosmina coregoni	n	4
	Bosmina longirostris	n	2
	nauplius	n	4
	Calanoida (unidentified)	n	4
	Cyclopoida (unidentified)	n	2
	Harpacticoida (unidentified)	n	2
GL-16-1 (12)	Hydrozoa medusa	y	8
	Keratella sp.	n	8
	Bosmina sp.	?	8
	Harpacticoida (unidentified)	y	133
GL-16-2	Keratella sp.	n	8
	Harpacticoida (unidentified)	y	117
	Amphipoda	y	8
GL-20-1 (7)	Anaitides sp. nectochaete	y	8
	Gastropoda veliger (Prosobranchia)	y	150
	Bivalvia veliger	y	567
	nauplius	y	5917
	Cyclopoida (unidentified)	?	2217
	Calanoida (unidentified)	?	2333
	Harpacticoida (unidentified)	y	8
	Cirripedia cypris	?	8
	Bryozoa cyphonautes	?	117
GL-20-2	Anaitides or Phyllodoce sp. nectochaete	y	4
	Trematoda?	y	7
	Gastropoda veliger (Prosobranchia)	y	193
	Bivalvia veliger	y	527
	nauplius	y	3322
	Calanoida (unidentified)	y	4636
	Cyclopoida (unidentified)	n	2926
	Harpacticoida (unidentified)	?	2
	Cirripedia nauplius	n	4
	Cirripedia cypris	?	2
	Decapoda	n	2
	Bryozoa cyphonautes	y	117

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-21-1 (8)	Bosmina coregoni	n	19
	Bosmina longirostris	n	19
GL-21-2	Keratella sp.	n	34
	Bosmina sp.	n	85
GL-23-1 (5)	Bivalvia veliger	y	8
	Bosmina sp.	n	8
	nauplius	y	4308
	Centropages typicus	y	158
	Calanoida (unidentified)	y	325
	Oithona similis	y	625
	Harpacticoida (unidentified)	n	8
GL-23-2	nauplius	?	6391
	Centropages typicus	?	174
	Calanoida (unidentified)	?	522
	Oithona similis	?	2000
GL-23-3	Hydrozoa colony	n	2
	Bivalvia veliger	n	2
	Bosmina sp.	n	4
	nauplius	y	682
	Centropages typicus	y	228
	Temora longicornis	y	4
	Calanus finmarchicus	y	7
	Calanoida (unidentified)	y	332
	Oithona similis	y	830
	Microsetella norvegica	n	2
	Gammarus ?tigrinus subadult	n	2
	Decapoda (Caridea)	y	2
	Chironomidae larva	?	2
	trochophore	y	2
GL-26-1 (11-13)	nauplius	n	28
	Cyclopoida (unidentified)	y	28
	Harpacticoida (unidentified)	?	28
GL-26-2	nauplius	?	9
	Cyclopoida (unidentified)	?	37
GL-26-3	Bivalvia veliger	n	2
	Cyclopoida (unidentified)	y	24
	Microsetella norvegica	n	2

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-32-1 (7)	Turbellaria	y	19
	Polydora complex metatrochophore II	y	9
	Gastropoda veliger (Prosobranchia)	y	28
	Bivalvia veliger	y	19
	nauplius	y	2299
	Acartia clausi	y	346
	Oithona similis	y	131
	Harpacticoida copepodite	y	28
	Dajidae	y	19
	Cirripedia cypris	y	28
	Cirripedia nauplius	y	19
GL-34-1 (8)	Gastropoda veliger	y	17
	Bivalvia veliger	y	67
	Rotifera	y	8
	Podon polyphemoides	n	8
	nauplius	y	11050
	Centropages typicus	y	25
	Calanus finmarchicus	y	25
	Calanoida copepodites	y	42
	Oithona similis	y	5983
	Cyclopoida (unidentified)	y	25
	Microsetella norvegica	y	208
	Euphausiacea protozoea	y	8
	Bryozoa cyphonautes	y	8
	Echinodermata ophiopluteus	y	133
GL-34-2	nauplius	y	133
	Calanus finmarchicus	y	25
	Centropages typicus	y	167
	Temora longicornis	y	150
	Calanoida (unidentified)	y	483
	Oithona similis	y	4017
	Microsetella norvegica	y	50
	Euphausiacea nauplius	y	8
	Euphausiacea protozoea	y	8
	Echinoderm ophiopluteus	y	58
	planula	?	8
GL-34-3	Bivalvia veliger	?	83
	nauplius	?	21000
	Calanoida copepodite	?	500
	Oithona similis	?	8042
	Microsetella norvegica	?	792

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-35-1 (1)	Keratella sp.	n	1
	Rotifera (unidentified)	y	1
	Nematoda	n	2
	?Spionidae metatrochophore I	n	<1
	Spiophanes sp. metatrochophore	n	<1
	Gastropoda veliger (Prosobranchia)	n	2
	Bivalvia veliger	n	28
	Bosmina coregoni	n	6
	Bosmina longirostris	n	12
	Chydorus brevilabris	n	18
	Camptocercus rectirostris	n	2
	Graptoleberis testudinaria	n	2
	Ostracoda	y	2
	nauplius	y	3008
	Acartia clausi	y	1237
	Eurytemora affinis	y	53
	Temora longicornis	y	501
	Calanoida (unidentified)	y	629
	Oithona sp.	y	3
	Microsetella norvegica	y	3445
	Cirripedia cypris	n	1
	Chironomidae larva	n	<1
	Platyhelminthes	y	5
GL-36-1 (>29)	Nematoda	n	8
	Keratella sp.	n	17
	Bosmina sp.	n	8
GL-36-2	Nematoda	n	17
	Gastropoda veliger (Prosobranchia)	n	8
	nauplius	n	17
	Harpacticoida (unidentified)	n	50
GL-40-1 (<7)	Keratella sp.	y	84
	Polyarthra remata	y	570
	Euchlanis sp.	y	355
	Rotifera (unidentified)	?	9
	Nematoda	y	168
	Chaetogaster diastrophus fragments	y	28
	Bosmina longirostris	y	9
	Chydorus brevilabris	?	9
	nauplius	y	159
	Eurytemora affinis	y	19
	Tropocyclops prasinus	y	9

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Diacyclops thomasi	y	28
	Bryocampus sp.	n	19
	trochophore	y	37
	Chironomidae adult	n	9
	unidentified	?	65
GL-40-2	Hydromedusa	y	9
	Keratella sp.	y	9
	Euchlanis sp.	y	65
	Lecane (Monostyla) sp.	y	28
	Rotifera (unidentified)	y	9
	Nematoda	y	9
	?Spionidae metatrochophore I	?	1
	Bosmina coregoni	y	28
	Chydorus sp.	y	37
	Alona affinis	y	9
	nauplius	y	140
	Eurytemora affinis	y	47
	Mesocyclops edax	y	65
	Bryocampus sp.	?	28
GL-41-1 (14)	Nematoda	y	14
	Keratella sp.	n	28
	nauplius	y	819
	Centropages velificatus	y	14
	Temora turbinata	y	69
	Calanoida (unidentified)	y	56
	Calanus sp.	y	28
	Calanoida copepodite	y	42
	Cyclopoida copepodite	y	694
	Harpacticoida (unidentified)	n	14
GL-41-2	Gastropoda veliger (Opisthobranchia)	y	14
	Bosmina coregoni	n	167
	Bosmina longirostris	n	181
	nauplius	y	639
	Calanoida (unidentified)	y	319
	Cyclopoida copepodite	y	778
GL-43-1 (8-9)	Keratella sp.	n	8
	nauplius	y	33
	Cyclopoida (unidentified)	n	17
	Harpacticoida (unidentified)	n	8

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
GL-43-2	Nematoda	?	2
	nauplius	y	2
	Cyclopoida (unidentified)	y	18
	Calanoida (unidentified)	?	2
	Harpacticoida (unidentified)	n	9
GL-44-1 (20)	nauplius	?	9
	Harpacticoida (unidentified)	y	28
GL-44-2	Harpacticoida (unidentified)	y	2
	unidentified (Platyhelminthes?)	y	2
GL-44-3	Keratella sp.	?	28
GL-48-1 (2)	Rotifera (unidentified)	y	50
	Gastropoda veliger (Prosobranchia)	y	225
	Bivalvia veligers	y	50
	nauplius	y	6800
	Temora longicornis	?	167
	Oithona similis	?	1633
	Microsetella norvegica	y	608
GL-48-2	Rotifera (unidentified)	y	2
	Gastropoda veliger (Prosobranchia)	y	60
	Bivalvia veliger	y	2
	Bosmina sp.	n	2
	nauplius	y	643
	Temora sp.	y	46
	Calanus finmarchicus	y	2
	Oithona similis	y	201
	Microsetella norvegica	y	34
GL-48-3	Rotifera (unidentified)	?	34
	Gastropoda veliger (Opisthobranchia?)	?	475
	Bivalvia veliger	?	169
	nauplius	?	8983
	Calanus finmarchicus	?	136
	Temora longicornis	?	68
	Oithona similis	?	1271
	Microsetella norvegica	?	339
	unidentified	?	17
GL-49-1 (2)	Gastropoda veliger	y	47
	Bivalvia veliger	y	9

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Rotifera	y	9
	nauplius	y	6467
	Calanus finmarchicus	y	47
	Calanoida (unidentified)	y	47
	Calanoida copepodite	y	84
	Oithona similis	y	1140
	Microsetella norvegica	y	1682
	Parathalestris croni	y	9
GL-49-2	Gastropoda veliger	y	65
	Rotifera	y	19
	nauplius	y	2355
	Calanus finmarchicus	y	56
	Temora longicornis	y	19
	Calanoida copepodite	y	84
	Oithona similis	y	1196
	Microsetella norvegica	y	243
	Echinodermata pluteus	n	9
GL-49-3	Rotifera (unidentified)	?	56
	Gastropoda veliger	?	278
	nauplius	?	8333
	Calanus finmarchicus	?	56
	Euchaeta norvegica	?	111
	Temora longicornis	?	56
	Oithona similis	?	1722
	Microsetella norvegica	?	2833
GL-51-1 (10)	NO ZOOPLANKTON		
GL-51-2	Nematoda	?	7
	Bosmina sp.	n	14
GL-54-1 (1-2)	Keratella sp.	y	36867
	Polyarthra sp.	y	417
	Kellicottia longispina	y	42
	Asplanchna sp.	y	642
	Euchlanis sp.	y	133
	Brachionus sp.	y	67
	Ceriodaphia quadrangula	y	57
	Daphnia retrocurva	y	169
	Daphnia galeata mendotae	y	57
	Bosmina coregoni	y	6433
	Bosmina longirostris	y	48233

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Chydorus sp. (sphaericus group)	y	25
	nauplius	y	1050
	Eurytemora affinis	y	75
	Skistodiaptomus oregonensis	y	25
	Diacyclops thomasi	y	2667
	Tropocyclops prasinus	y	267
	Cyclopoida (copepodite)	y	208
	Harpacticoida (unidentified)	?	8
GL-54-2	Keratella sp.	y	18
	Asplanchna sp.	y	101
	Acarina	y	2
	Daphnia retrocurva	y	99
	Bosmina coregoni	y	2735
	Bosmina longirostris	y	34184
	Chydorus sp. (sphaericus group)	y	2
	nauplius	y	39
	Eurytemora affinis	y	239
	Diacyclops thomasi	y	4438
	Mesocyclops edax	y	28
	Tropocyclops prasinus	y	254
	Cyclopoida (copepodite)	y	876
	Coleoptera (unidentified)	n	2
GL-55-1 (1-4)	Keratella	n	28
	Daphnia galeata mendotae	y	69
	Bosmina coregoni	y	278
	Bosmina longirostris	y	1139
	Bosmina longispina	y	861
	nauplius	y	278
	Skistodiaptomus oregonensis	y	1222
	Eurytemora affinis	y	278
	Calanoida (copepodite)	y	333
	Diacyclops thomasi	y	847
	Tropocyclops prasinus	y	722
	Cyclopoida (copepodite)	y	847
GL-55-2	Keratella sp.	n	3
	Daphnia galeata mendotae	y	15
	Bosmina longispina	y	611
	Bosmina longirostris	y	853
	Chydorus brevilabris	y	3
	nauplius	y	71
	Skistodiaptomus oregonensis	y	1086

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Eurytemora affinis	y	83
	Diacyclops thomasi	y	1522
	Tropocyclops prasinus	y	448
GL-55-3	Daphnia galeata mendotae	?	417
	Bosmina coregoni	?	833
	Bosmina longirostris	?	833
	nauplius	?	833
	Skistodiaptomus oregonensis	?	3083
	Diacyclops thomasi	?	2750
	Tropocyclops prasinus	?	500
GL-56-1 (17)	Bosmina coregoni	n	9
	Calanoida (unidentified)	?	9
GL-56-2	Keratella sp.	n	2
	Kellicottia longispina	n	2
	Gastropoda veliger	n	2
	Bosmina sp.	n	4
GL-56-3	NO ZOOPLANKTON		
GL-57-1 (0: same day)	Rotifera (unidentified)	n	7
	Nematoda	y	7
	Bosmina longirostris	?	7
	nauplius	y	91
	Eurytemora affinis	y	105
GL-57-2	nauplius	y	49
	Eurytemora affinis	y	70
GL-58-1 (8)	Gastropoda veliger	?	14
	nauplius	?	14
GL-58-2	nauplius	n	167
	Calanoida copepodite	?	83
GL-58-3	Bosmina sp.	n	9
MH-1-1	Hydrozoa polyp	?	8
	Keratella sp.	?	25
	Rotifera (unidentified)	?	40
	Nematoda	?	45
	Chaetogaster diastrophus	?	8

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Polyarthra remata	?	205
	Daphnia sp.	?	8
	Bosmina sp.	?	8
	nauplius	?	100
	Eurytemora affinis	?	10
	Harpacticoida (unidentified)	?	25
	Gammarus sp. immature	?	8
MH-1-2	Euchlanis sp.	y	2
	Rotifera (unidentified)	y	2
	Chaetogaster diastrophus	?	2
	Nais ?elinguis	?	2
	Bivalvia veliger (?)	?	2
	Acarina (unidentified)	?	2
	Bosmina longirostris	?	12
	Bosmina coregoni	?	4
	nauplius	y	44
	Eurytemora affinis	y	9
	Macrocyclops albidus	y	5
	Harpacticoida (unidentified)	y	12
	Gammarus sp. immature	?	2
	Chironomidae larva	y	9
MH-2-1	Keratella sp.	?	408
	Polyarthra remata	?	533
	Trichocerca sp.	?	25
	Rotifera (unidentified)	?	142
	Nematoda	?	83
	Aeolosoma sp.	?	17
	Chaetogaster setosus	?	17
	Nais behningi	?	17
	Bosmina longirostris	?	25
	Bosmina coregoni	?	25
	nauplius	?	308
	Eurytemora affinis	?	33
	Cyclopoida (unidentified)	?	25
	Harpacticoida (unidentified)	?	33
MH-2-2	Rotifera (unidentified)	?	2
	Nematoda	y	5
	Polychaeta (damaged)	n	2
	Chaetogaster setosus	y	4
	Bosmina coregoni	?	9
	Bosmina longirostris	?	19

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
	Chydorus sphaericus	?	5
	nauplius	y	37
	Eurytemora affinis	y	12
	Tropocyclops prasinus	y	11
	Harpacticoida (unidentified)	y	5
	Chironomidae larva	y	2
	unidentified (larval acoel?)	y	2
MH-3-1	Keratella sp.	?	25
	Euchlanis sp.	?	375
	Lecane (=Monostyla) sp.	?	125
	Polyarthra remata	?	175
	Nematoda	?	100
	Chaetogaster sp.	?	19
	Nais behningi	?	19
	Naididae fragments	?	19
	Bosmina coregoni	?	8
	Bosmina longirostris	?	17
	Chydorus brevilabris	?	8
	Alona costata	?	8
	nauplius	?	150
	Eurytemora affinis	?	8
	Macrocyclops albidus	?	17
MH-3-2	Euchlanis sp.	?	21
	Nematoda	?	46
	Chaetogaster diastrophus	?	3
	Chaetogaster limnaei	?	5
	Nais behningi	?	3
	?Nais sp. fragments	?	3
	Naididae fragments	?	7
	Oligochaeta (unidentified)	?	3
	Acarina (Aturus sp.)	?	2
	Moina sp. (?hartwigi)	?	2
	Diaphanosoma sp.	?	2
	Bosmina coregoni	?	7
	Chydorus brevilabris	?	2
	Chydoridae	?	2
	nauplius	?	37
	Eurytemora affinis	?	19
	Cyclopoida copepodite	?	5
	Gammarus sp. immature	?	2
	Chironomidae larva	?	2

Appendix K. (continued)

SAMPLE	TAXON	ANY ALIVE?	n m^{-3}
MH-4-1	Euchlanis sp.	?	633
	Keratella sp.	?	192
	Polyarthra remata	?	1233
	Nematoda	?	208
	Aeolosoma sp.	?	2
	Chaetogaster diastrophus	?	2
	Nais behningi	?	2
	Naididae fragments	?	2
	Bosmina coregoni	?	17
	Bosmina longirostris	?	25
	Chydorus brevilabris	?	8
	nauplius	?	292
	Tropocyclops prasinus	?	8
	Harpacticoida (unidentified)	?	17
	?Larvacean	?	8
MH-4-2	Polyarthra remata	?	4
	Euchlanis sp.	?	39
	Nematoda	?	14
	Oligochaeta	?	18
	Bosmina coregoni	?	4
	Bosmina longirostris	?	2
	Graptoleberis testudinaria	?	5
	Ostracoda	?	2
	nauplius	?	25
	Eurytemora affinis	?	7
	Tropocyclops prasinus	?	12
	Harpacticoida (unidentified)	?	2
	Insecta unidentified fragments	n	2

Appendix L. Qualitative analysis of zooplankton samples before preservation, including samples from vessels which had originated in a saltwater port and exchanged ballast in salt water (or had no previous ballast water and took on water in salt water). The nember of days elapsed since the previous major introduction of water to the tank sampled is recorded after the first sample code for each ship. (Abundances listed as r (rare) = 1 - 4; f (few) = 5 - 9; c (common) = 10 - 100; a (abundant) > 100).

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
GL-1-1 (13-14)	Gastropoda veliger	y	r
	Bivalvia veliger	n	r
	Bosmina sp.	n	r
	nauplius	y	f
	copepodites	y	f
	Cyclopoida	y	r
	Calanoida	y	r
	Harpacticoida	y	r
GL-1-2	Bivalvia veliger	n	r
	Bosmina sp.	n	r
	nauplius	y	f
	copepodites	y	r
	Calanoida	y	r
	Cyclopoida	y	r
GL-2-1 (5)	Keratella sp.	n	r
	Bosmina sp.	n	r
	nauplius	y	f
	Calanoida	n	f
	Cyclopoida	y	r
	Harpacticoida	y	r
	Cirripedia nauplius	y	f
	Cirripedia cypris	y	r
GL-2-2	Bosmina sp.	n	r
	Calanoida (Acartia)	n	f
	Cirripedia cypris	y	r
GL-4-1 (5)	Keratella sp.	n	f
	Kellicottia sp.	n	r
	Bosmina sp.	n	r
	Cyclopoida	y	r
	Harpacticoida	n	r
GL-4-3	Keratella sp.	n	r
	Cyclopoida	n	r

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
GL-5-1 (5)	Hydrozoa	n	r
	Keratella sp.	n	c
	Kellicottia sp.	n	f
	Bosmina sp.	n	r
	nauplius	n	r
	Cyclopoida	y	f
	Harpacticoida	n	r
	Diptera	n	r
GL-8-1 (4)	Rotifera	y	r
	Nematoda	y	r
	Polychaeta	y	r
	nauplius	y	c
	Cyclopoida	y	f
	Calanoida	y	r
GL-9-1 (2-3)	Keratella sp.	n	f
	Nematoda	y	r
	Bivalvia veligers	n	f
	Bosmina sp.	n	r
	Ostracoda	y	r
	nauplius	n	c
	Calanoida	y	r
	Harpacticoida	n	r
	Isopoda (?)	n	r
	Insecta	n	r
GL-10-1 (10)	Hydrozoa	n	r
	Rotifera	n	f
	Nematoda	y	r
	Cladocera	n	r
	nauplius	n	c
	Calanoida	n	r
	Cyclopoida	y	r
GL-11-1 (7-8)	nauplius	y	c
	Calanoida	n	r
	Cyclopoida (Oithona)	y	f
	Harpacticoida	n	c
GL-11-2	Bosmina sp.	n	r
	Calanoida	y	f
	Cyclopoida	y	r

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
	Harpacticoida	y	r
	trochophore	y	r
GL-12-1 (5)	Gastropoda veligers	n	f
	Bivalvia veligers	n	f
	nauplius	y	f
	Calanoida	y	r
	Cyclopoida	y	f
	Harpacticoida	y	r
GL-12-2	Polychaeta	n	r
	Gastropoda veligers	n	c
	Bivalvia veligers	n	f
	nauplius	y	c
	Calanoida	y	r
	Cyclopoida (Oithona)	y	c
	Harpacticoida	n	r
	Decapoda pre-zoea	n	r
GL-14-1 (5)	Gastropoda veligers	n	r
	Rotifera	y	f
	nauplius	y	a
	Calanoida	n	r
	Cyclopoida	y	c
GL-14-2	Gastropoda veliger	n	r
	Bosmina sp.	n	r
	nauplius	y	c
	Calanoida	n	r
	Cyclopoida (Oithona)	y	c
GL-15-1 (6-8)	Keratella sp.	n	r
	nauplius	y	c
	Calanoida	y	r
	Cyclopoida	y	f
	Harpacticoida	y	r
GL-15-2	Nematoda	y	r
	nauplius	y	c
	Calanoida	y	r
	Cyclopoida	y	c

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
	Harpacticoida	y	f
	Decapoda zoea	y	r
GL-17-1 (4)	nauplius	y	a
	Calanoida	y	c
	Cyclopoida	y	a
	Gammaridea	y	r
GL-17-2	Gastropoda veliger	n	r
	Bosmina sp.	n	r
	nauplius	y	c
	Calanoida	y	f
	Cyclopoida	y	c
GL-18-1 (7)	Nematoda	y	r
	nauplius	y	r
	Cyclopoida	y	r
	Harpacticoida	y	r
GL-18-2	NO ZOOPLANKTON		
GL-19-1 (14)	Harpacticoida	y	r
GL-19-2	Bivalvia veliger	n	r
	Harpacticoida	y	r
GL-22-1 (5)	Nematoda	y	r
	nauplius	n	r
	Cyclopoida	y	r
	Harpacticoida	y	r
GL-24-1 (8)	nauplius	n	c
GL-24-2	NO ZOOPLANKTON		
GL-25-1 (4)	Bivalvia veliger	n	r
	nauplius	y	r
	Calanoida	y	r
	Cyclopoida	y	r
	Harpacticoida	y	r
	trochophore	y	f

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
GL-25-2	Gastropoda veliger	n	r
	Bivalvia veliger	n	r
	Bosmina sp.	n	r
	nauplius	y	r
	Calanoida	y	r
	Cyclopoida	y	r
	Harpacticoida	y	f
	Decapoda megalopa (Brachyura)	y	r
	trochophore	y	r
GL-27-1 (7-8)	Polychaeta	y	c
	Bivalvia veliger	y	f
	nauplius	y	c
	copepodites	y	c
	Calanoida	y	r
	Cyclopoida (Oithona)	y	f
	Cirripedia cypris	y	r
GL-27-2	Polychaeta	y	c
	Bivalvia veliger	y	c
	Cladocera	n	r
	nauplius	y	c
	copepodites	y	c
	Calanoida	y	f
	Cyclopoida	y	f
	Cirripedia cypris	y	r
GL-28-1 (5-6)	nauplius	y	r
GL-28-2	nauplius	y	r
	Harpacticoida	y	r
GL-29-1 (4-5)	Turbellaria	y	c
	Keratella sp.	n	r
	nauplius	y	f
	copepodites	y	
	Cyclopoida	y	r
GL-29-2	Cyclopoida	y	r
GL-30-1 (31-32)	Rotifera	y	c
	Bivalvia veliger	y	f
	nauplius	y	a

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
	copepodites	y	a
	Calanoida	y	r
	Cyclopoida	y	c
GL-30-2	Rotifera	y	c
	Gastropoda veliger	y	r
	Bivalvia veliger	y	f
	Cladocera	n	r
	nauplius	y	a
	Calanoida	y	a
	Cyclopoida (Oithona)	y	c
GL-31-1 (2)	Rotifera	y	r
	Gastropoda veliger	y	r
	Bivalvia veliger	y	c
	nauplius	y	a
	Calanoida	y	a
	Cyclopoida	y	c
	Harpacticoida	y	f
	Echinodermata pluteus	y	r
	unidentified	y	r
GL-31-2	Bivalvia veliger	y	r
	nauplius	y	a
	copepodites	y	a
	Calanoida	y	r
	Cyclopoida	y	c
	Harpacticoida	y	r
GL-33-1 (6)	Turbellaria	y	r
	Nematoda	y	r
	nauplius	y	r
	Cyclopoida	y	r
GL-33-2	nauplius	y	r
	Cyclopoida	y	r
GL-37-2 (5)	Polychaeta	y	r
	nauplius	y	a
	Calanoida	y	f
	Cyclopoida	y	c

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
	Harpacticoida	y	c
	Bryozoa cyphonautes	y	r
GL-37-3	nauplius	y	c
	copepodites	y	c
	Calanoida	y	f
	Cyclopoida	y	c
	Harpacticoida	y	r
	Cirripedia cypris	n	r
	Bryozoa cyphonautes	y	r
	Chaetognatha	y	r
GL-38-2 (7-8)	Hydromedusa	y	r
	Polychaeta	y	a
	nauplius	y	a
	copepodites	y	c
	Calanoida	y	r
	Cyclopoida	y	c
	Cirripedia nauplius	y	r
	Cirripedia cypris	y	r
GL-38-3	Hydromedusa	y	r
	Polychaeta	y	a
	Cirripedia nauplius	y	f
	nauplius	y	c
	copepodites	y	c
	Calanoida	y	c
	Cyclopoida (Oithona)	y	r
	Harpacticoida	y	r
	Mysidacea	y	r
	Cirripedia cypris	n	f
GL-39-1 (6)	Hydrozoa	n	r
	Nematoda	y	c
	Bivalvia veliger	n	r
	Cyclopoida	n	r
GL-39-2	NO ZOOPLANKTON		
GL-42-1 (41)	Cyclopoida	y	r

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
GL-42-2	Bosmina sp.	n	r
	Cyclopoida	y	r
	Cirripedia cypris	y	r
	Tardigrada	y	r
GL-45-1 (7)	Bosmina sp.	n	r
	nauplius	y	c
	Calanoida	y	r
	Cyclopoida	y	f
	Harpacticoida	y	r
GL-45-2	Bivalvia veliger	n	r
	nauplius	y	f
	copepodites	y	c
	Calanoida	y	r
	Cyclopoida	y	f
GL-46-1 (1)	Nematoda	y	r
	nauplius	y	c
	Calanoida	y	r
	Harpacticoida	n	r
GL-46-2	Nematoda	y	r
	nauplius	y	c
	Calanoida	y	f
	Cyclopoida (Oithona)	y	c
	Harpacticoida	y	r
GL-47-2 (9)	nauplius	y	c
	Calanoida	n	r
	Cyclopoida	y	f
GL-47-3	Cyclopoida	y	r
GL-50-1 (5)	nauplius	y	r
GL-50-2	nauplius	n	r
	Cyclopoida (Oithona)	n	r
GL-52-1 (10-11)	Nematoda	y	r
	Polychaeta	y	r
	nauplius	y	r
	Calanoida	n	r

Appendix L. (continued)

SAMPLE	TAXON	ANY ALIVE?	ABUNDANCE
	Cyclopoida	y	r
	Cirripedia nauplius	n	r
GL-52-2	Polychaeta	y	c
	nauplius	y	f
	Calanoida (Acartia)	n	c
	Cyclopoida	y	r
	Cirripedia nauplius	n	r
GL-53-1 (35)	NO ZOOPLANKTON		
GL-53-2	Bosmina sp.	n	r
GL-59-1 (8-9)	nauplius	y	c
	Calanoida	y	r
	Cyclopoida	y	r
GL-59-2	Cladocera	n	r
	nauplius	y	f
	copepodite	y	f
	Cyclopoida	y	r
	Harpacticoida	n	r